



US009329372B2

(12) **United States Patent**  
**Shimomura**

(10) **Patent No.:** **US 9,329,372 B2**  
(45) **Date of Patent:** **May 3, 2016**

(54) **ZOOM LENS AND IMAGE PICKUP  
APPARATUS HAVING THE SAME**

(71) Applicant: **CANON KABUSHIKI KAISHA,**  
Tokyo (JP)

(72) Inventor: **Kazuya Shimomura,** Utsunomiya (JP)

(73) Assignee: **CANON KABUSHIKI KAISHA,**  
Tokyo (JP)

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 101 days.

(21) Appl. No.: **14/452,615**

(22) Filed: **Aug. 6, 2014**

(65) **Prior Publication Data**

US 2015/0042846 A1 Feb. 12, 2015

(30) **Foreign Application Priority Data**

Aug. 8, 2013 (JP) ..... 2013-164807

(51) **Int. Cl.**

**G02B 15/14** (2006.01)

**G02B 15/20** (2006.01)

**G02B 13/00** (2006.01)

**G02B 15/177** (2006.01)

(52) **U.S. Cl.**

CPC ..... **G02B 15/20** (2013.01); **G02B 13/002**  
(2013.01); **G02B 13/009** (2013.01); **G02B**  
**15/177** (2013.01)

(58) **Field of Classification Search**

CPC .... G02B 15/20; G02B 13/009; G02B 13/002;  
G02B 15/177

USPC ..... 359/686–688

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0044576 A1\* 2/2012 Okumura ..... G02B 15/173  
359/686

2013/0271850 A1\* 10/2013 Shimomura ..... G02B 15/173  
359/687

FOREIGN PATENT DOCUMENTS

JP S63281113 A 11/1988

JP H04051006 A 2/1992

JP H05297276 A 11/1993

\* cited by examiner

*Primary Examiner* — Bumsuk Won

*Assistant Examiner* — Tamara Y Washington

(74) *Attorney, Agent, or Firm* — Carter, DeLuca, Farrell &  
Schmidt, LLP

(57) **ABSTRACT**

A zoom lens includes, in order from an object side: a negative first lens unit which does not move for zooming; a positive second lens unit which moves during the zooming; a negative third lens unit which moves during the zooming; and a positive fourth lens unit, wherein the following expressions are satisfied:

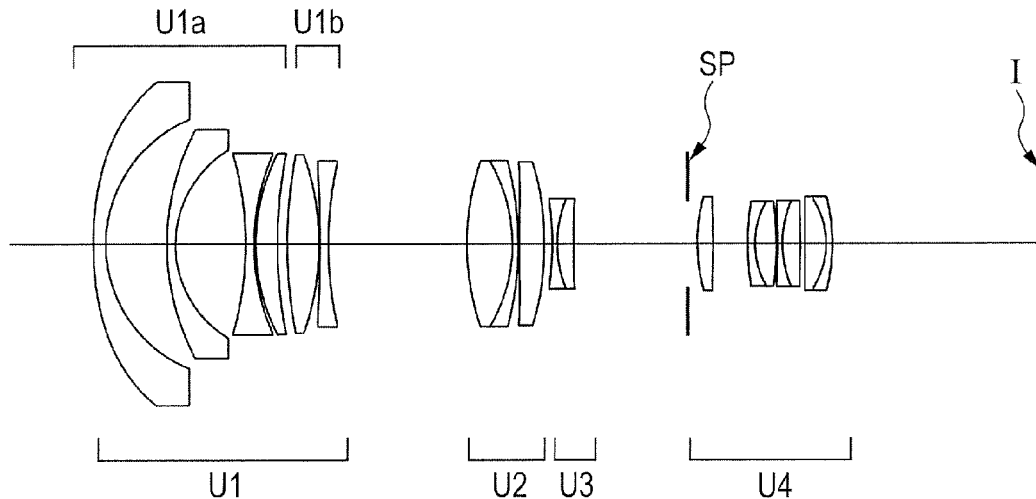
$$-0.80 < f_1/f_2 < -0.25,$$

$$-1.2 < f_2/f_3 < -0.4, \text{ and}$$

$$0.5 < |m_2/m_3| < 3.0,$$

where  $f_1$  represents a focal length of the first lens unit,  $f_2$  represents a focal length of the second lens unit,  $f_3$  represents a focal length of the third lens unit,  $m_2$  represents a moving amount of the second lens unit during the zooming from a wide angle end to a telephoto end, and  $m_3$  represents a moving amount of the third lens unit during the zooming from the wide angle end to the telephoto end.

**8 Claims, 15 Drawing Sheets**



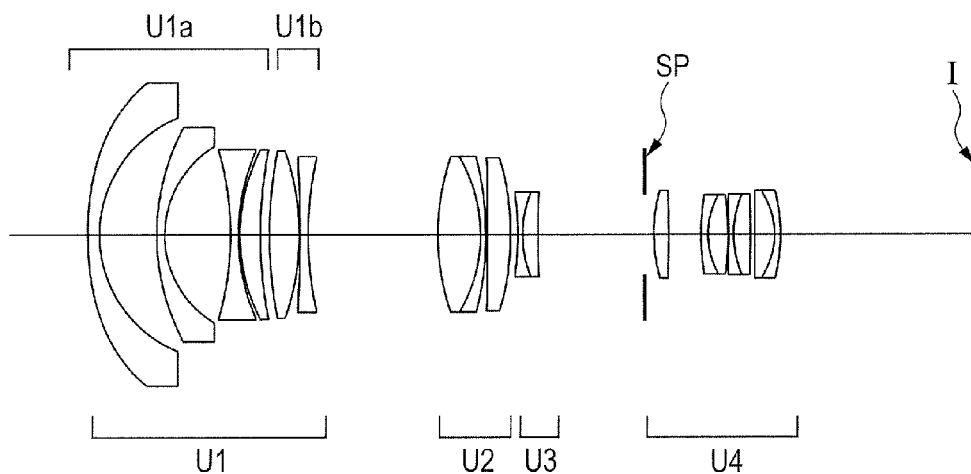
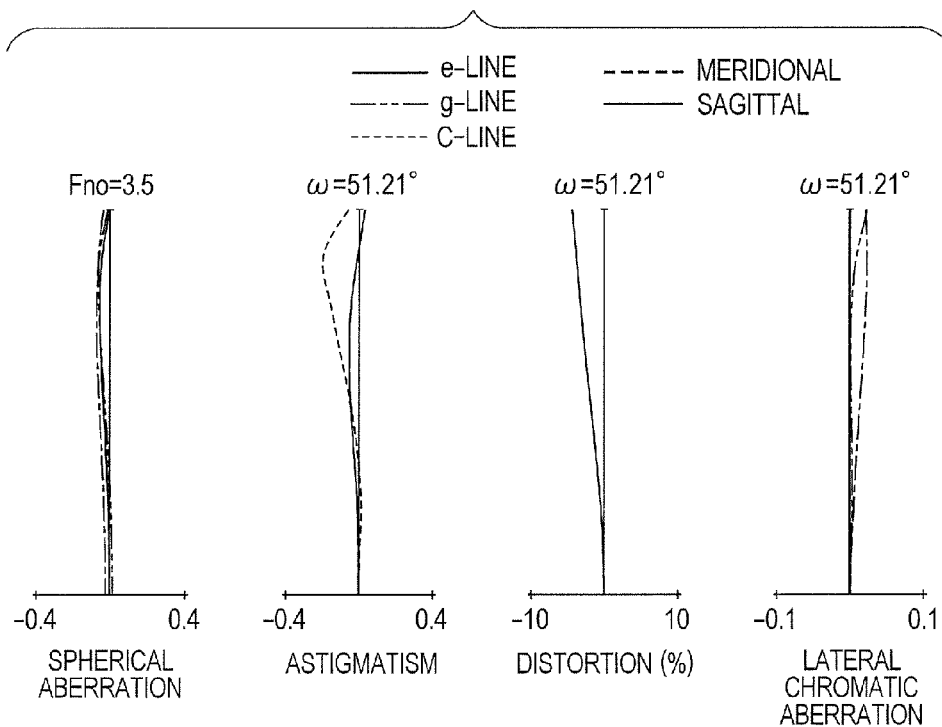
**FIG. 1****FIG. 2A**

FIG. 2B

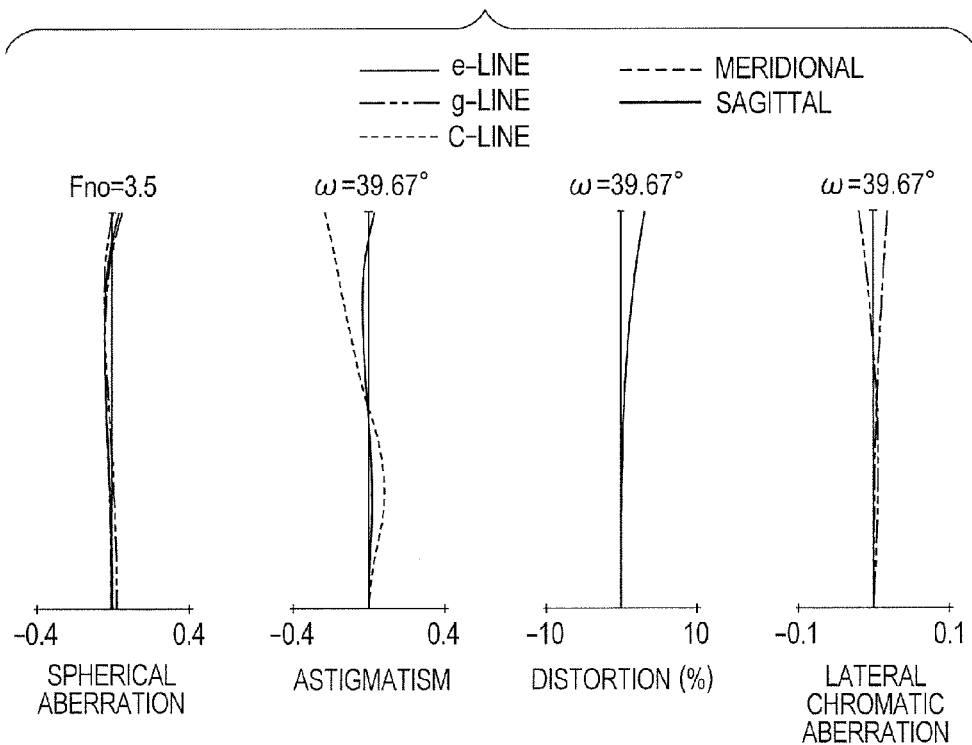


FIG. 2C

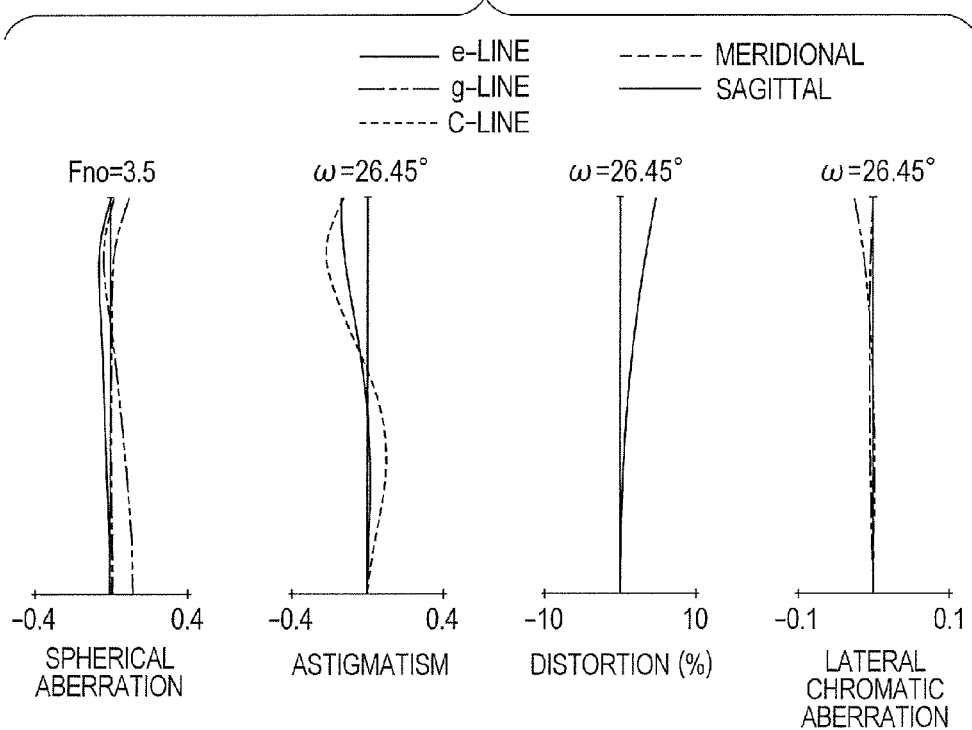


FIG. 3

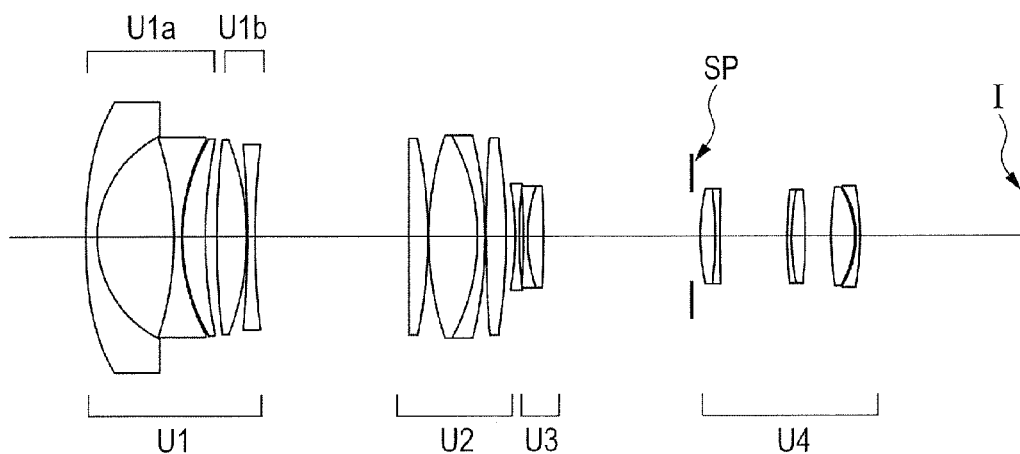


FIG. 4A

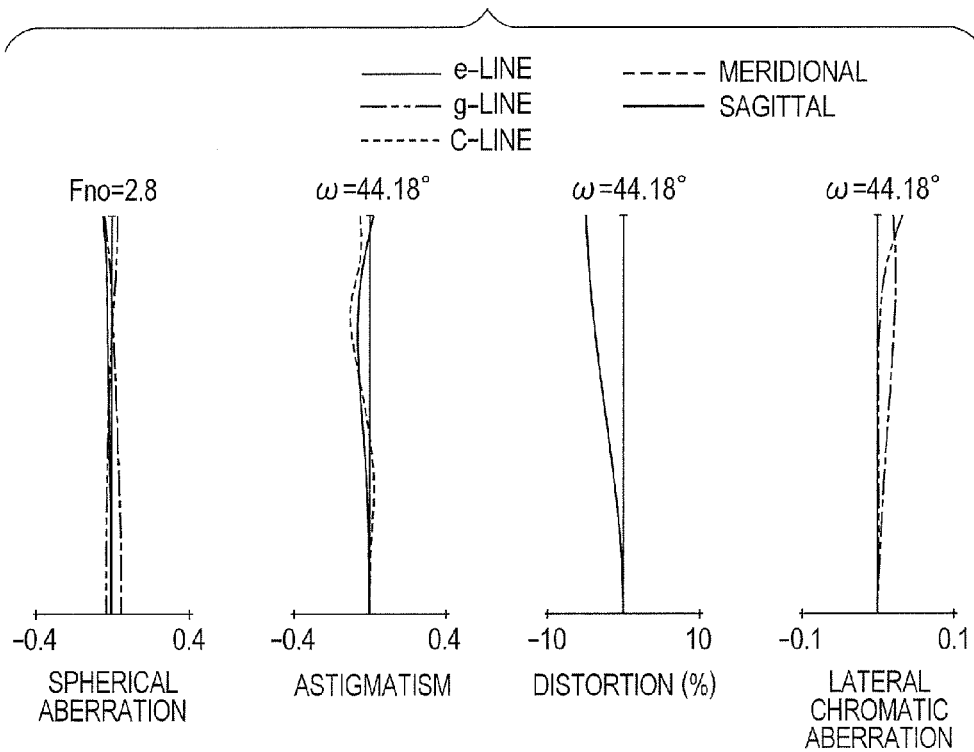


FIG. 4B

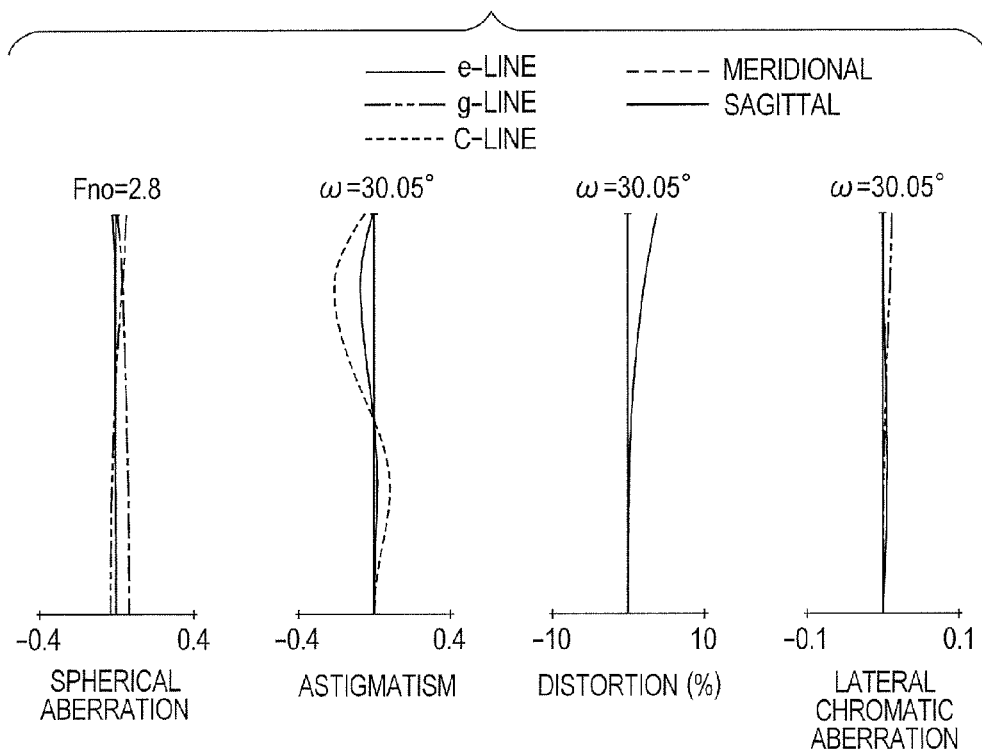
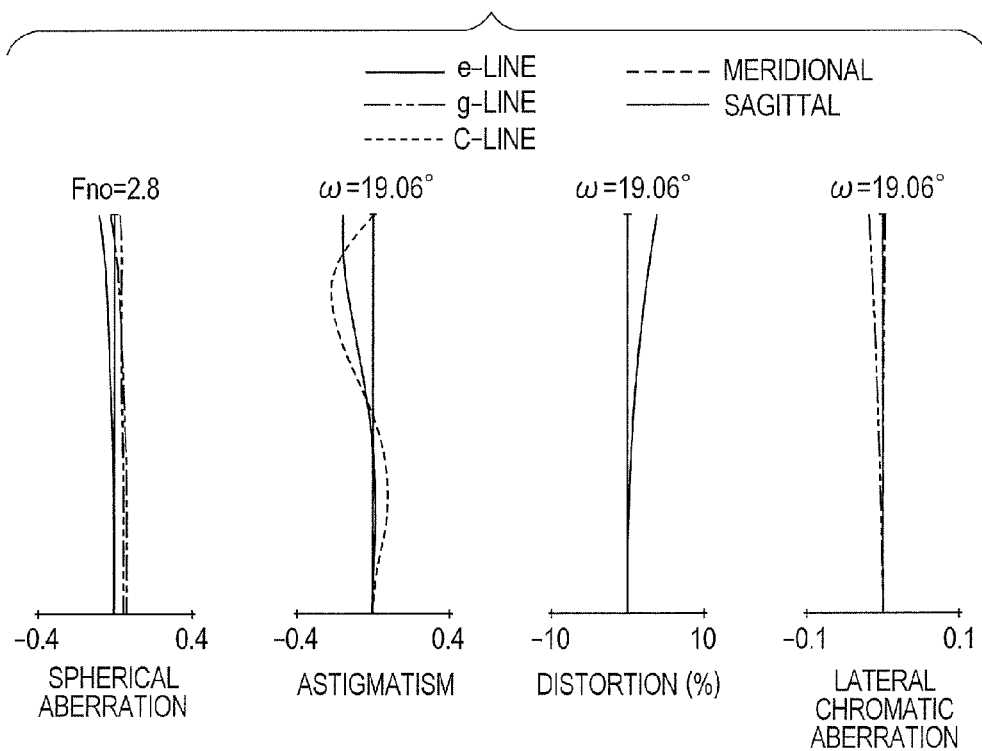
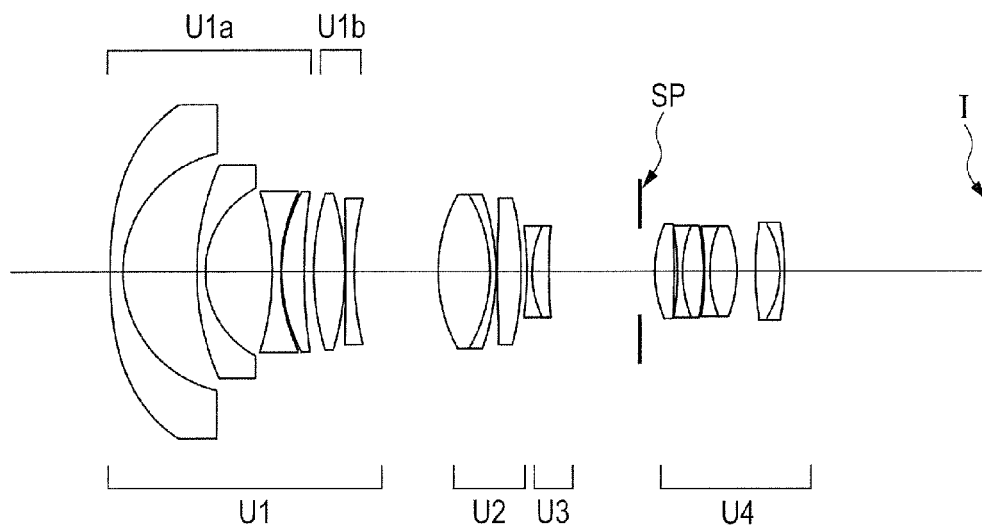
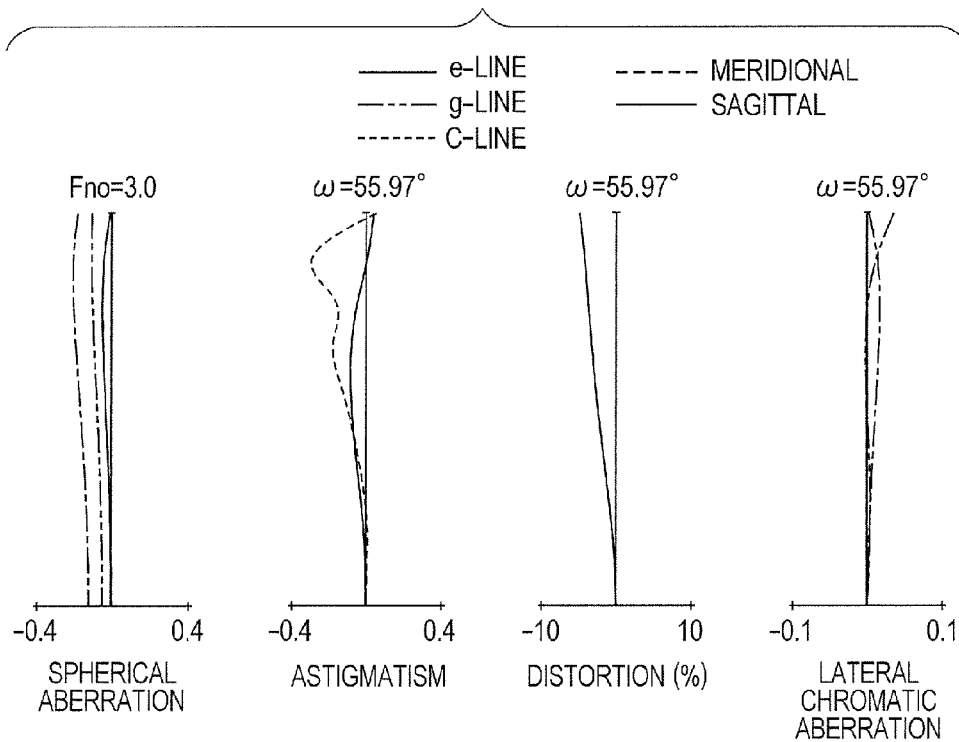


FIG. 4C



**FIG. 5****FIG. 6A**

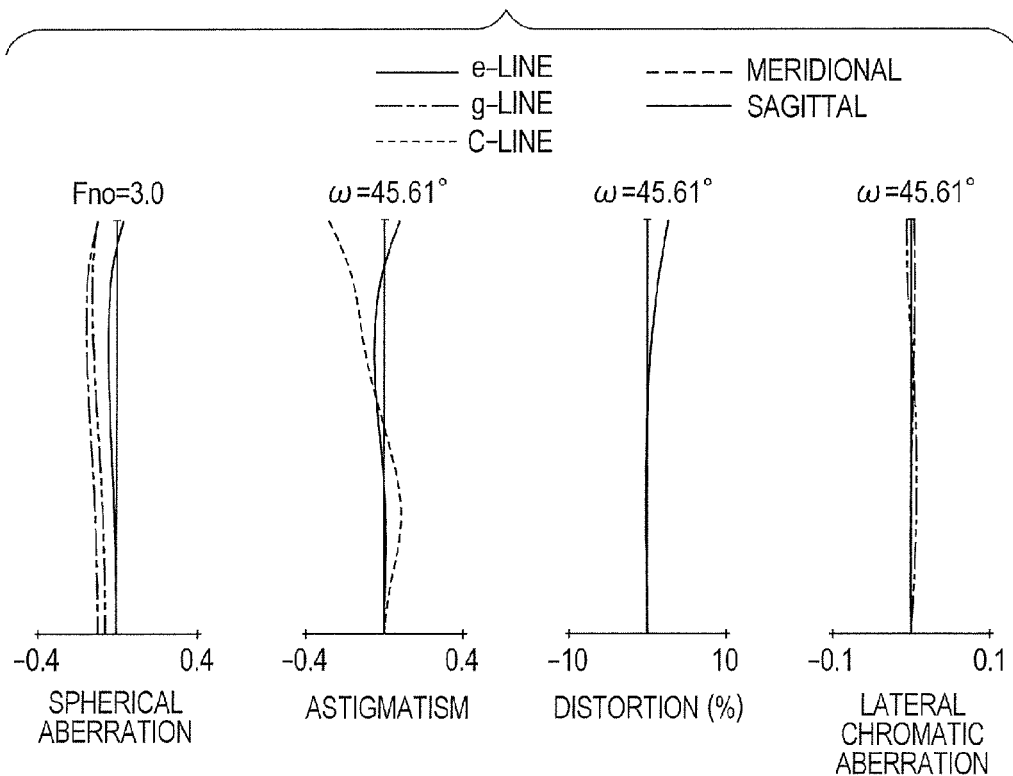
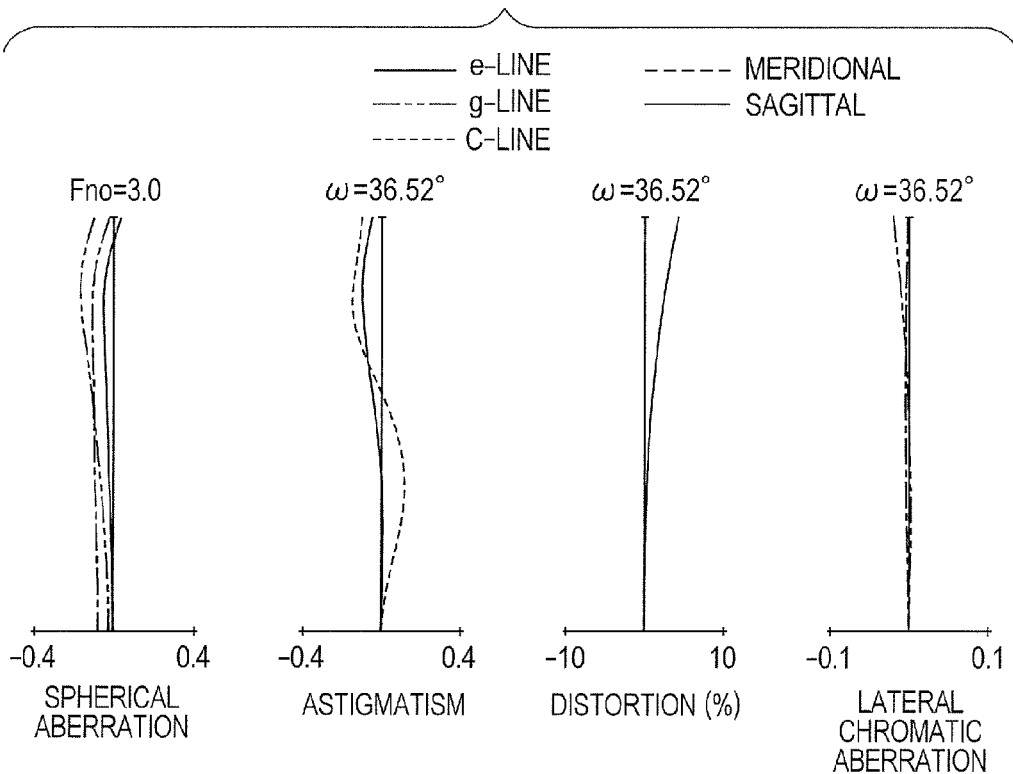
*FIG. 6B**FIG. 6C*

FIG. 7

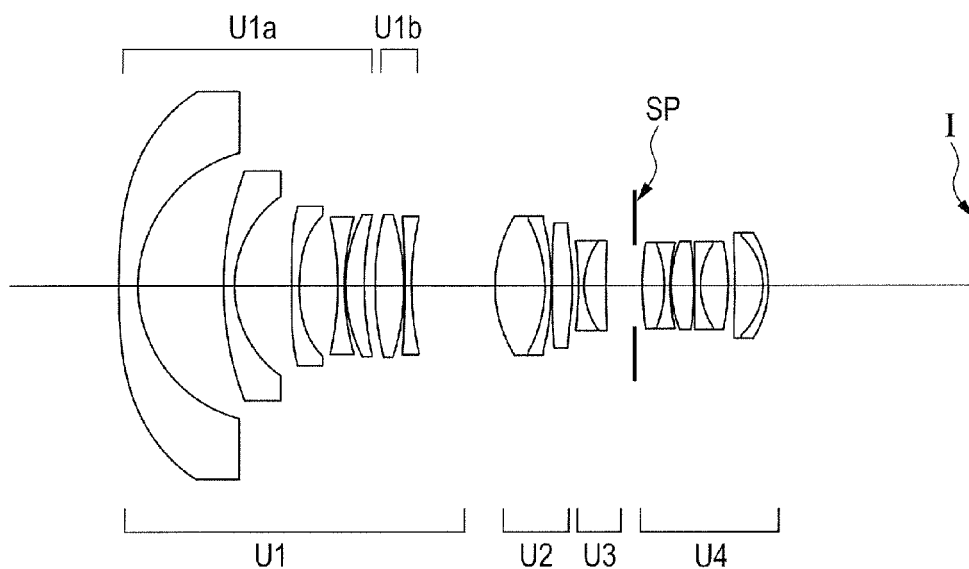


FIG. 8A

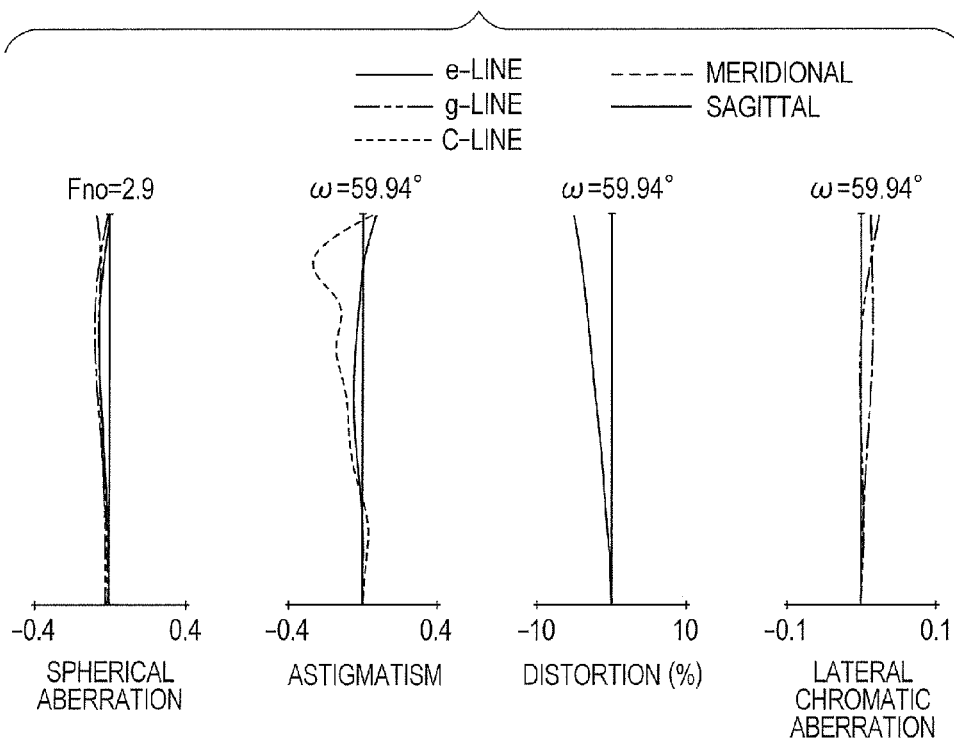




FIG. 8B

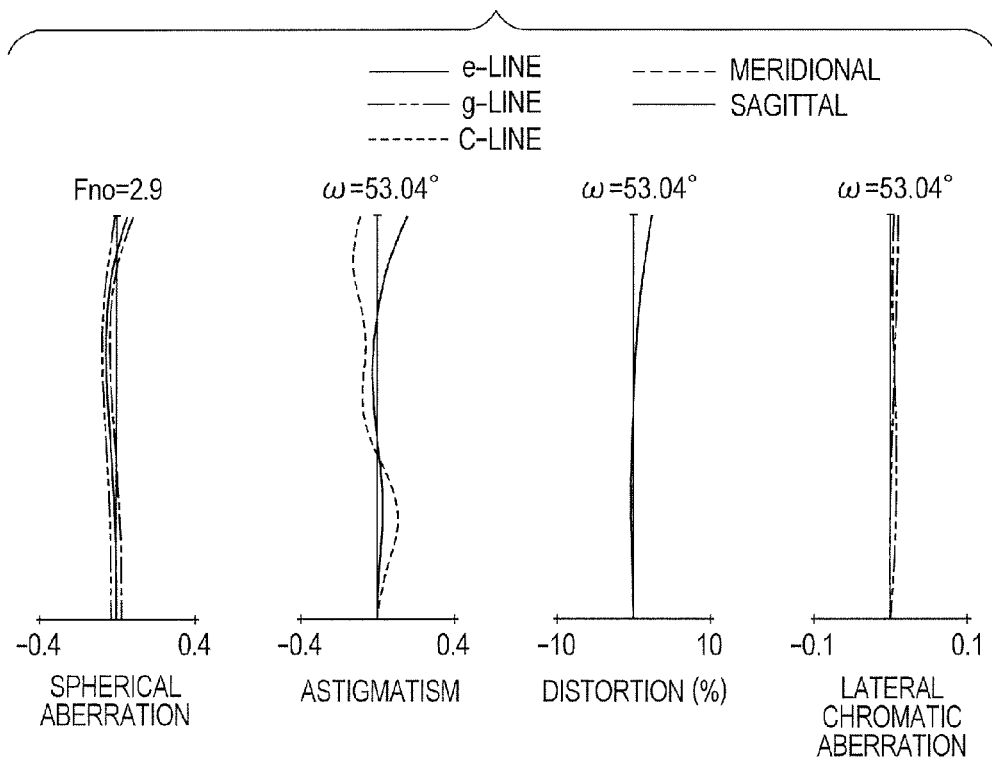


FIG. 8C

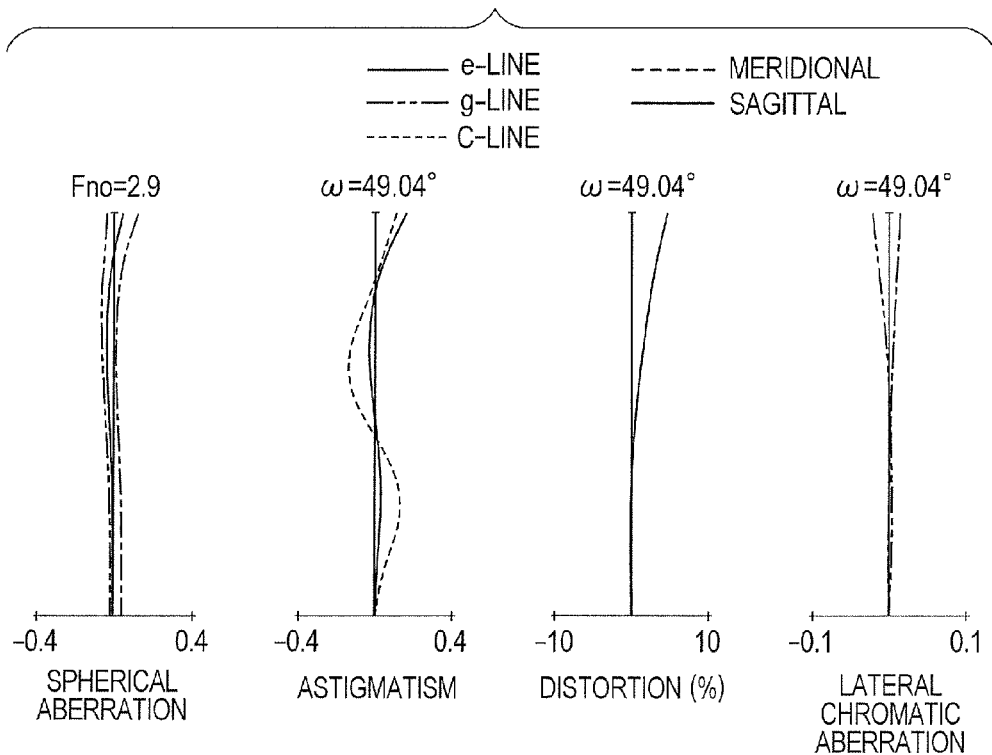


FIG. 9

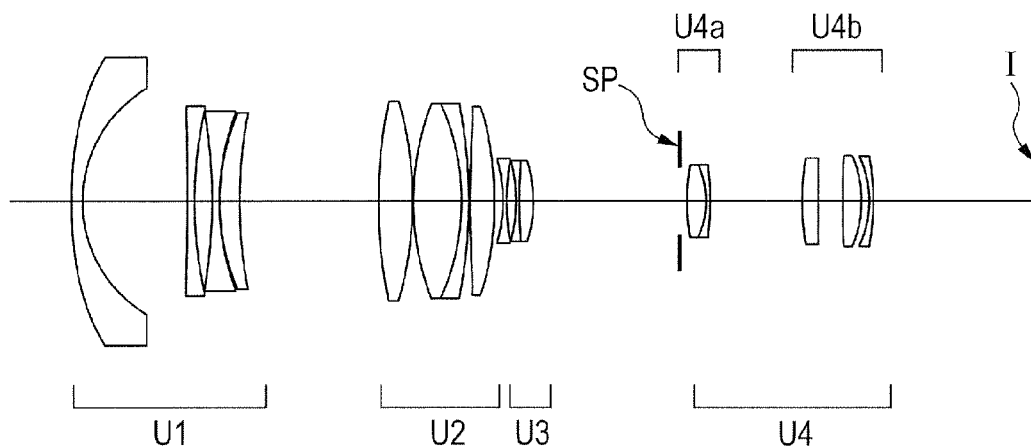


FIG. 10A

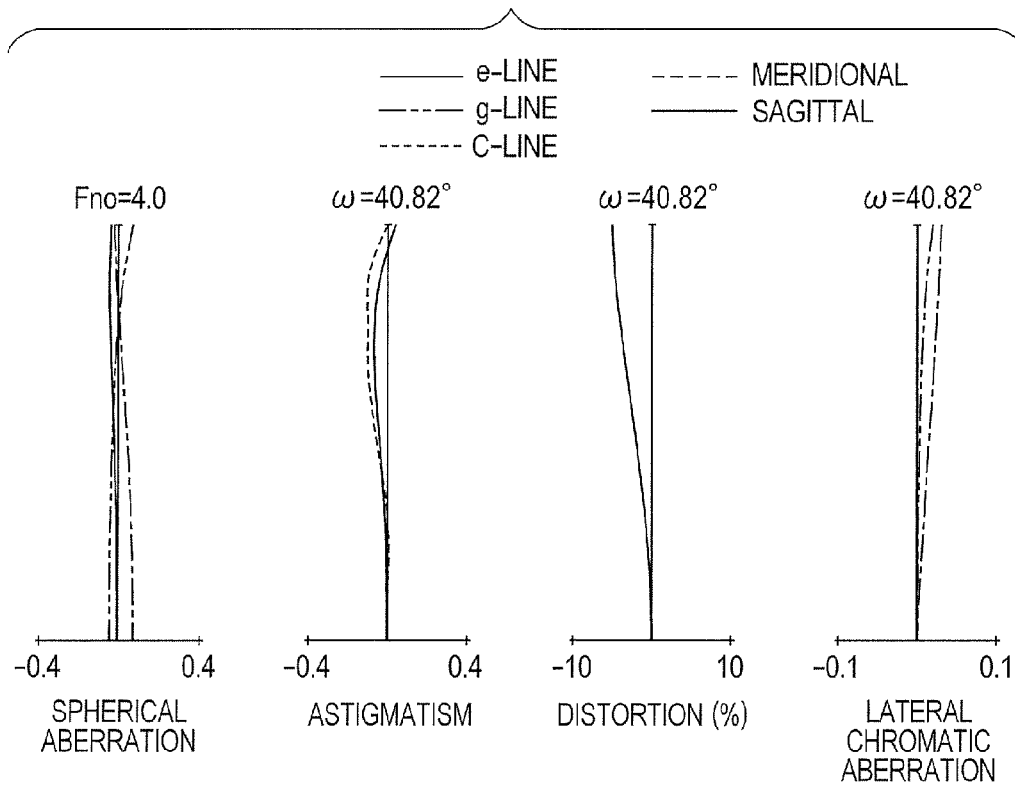


FIG. 10B

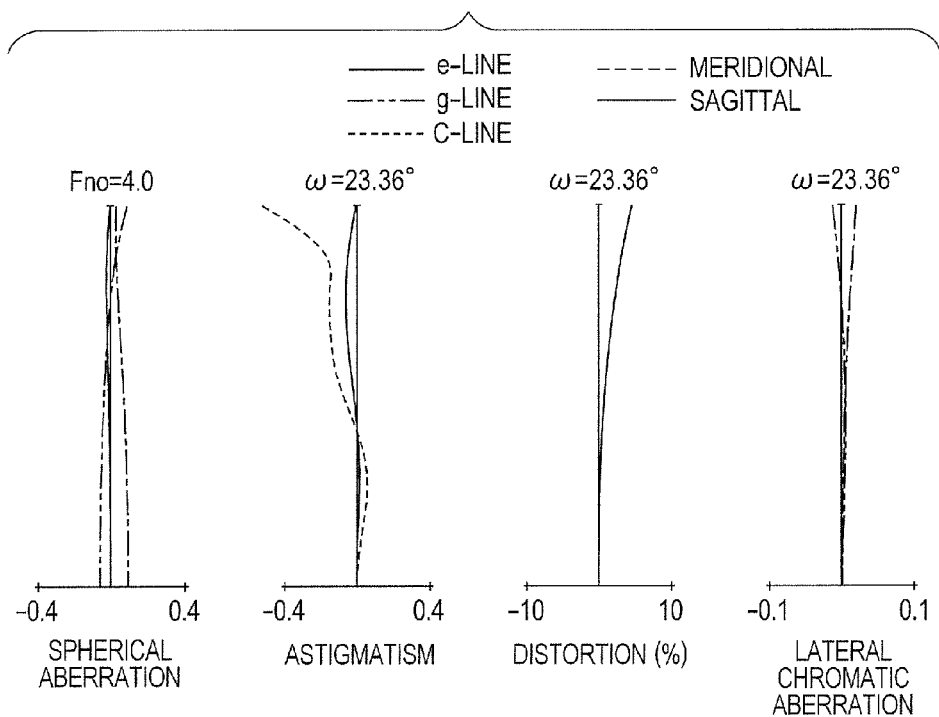


FIG. 10C

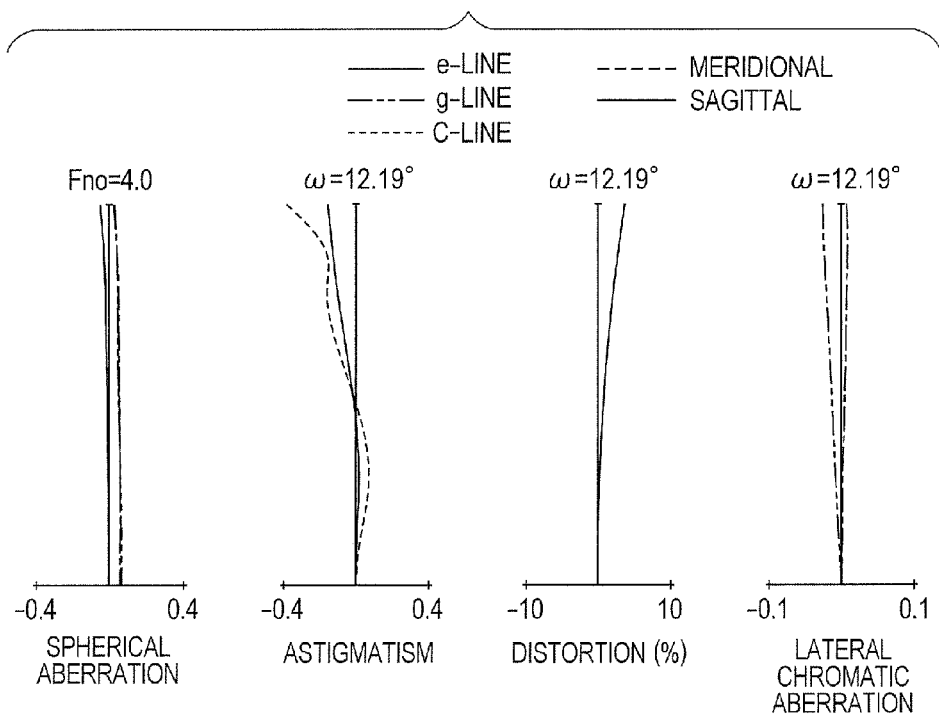


FIG. 11

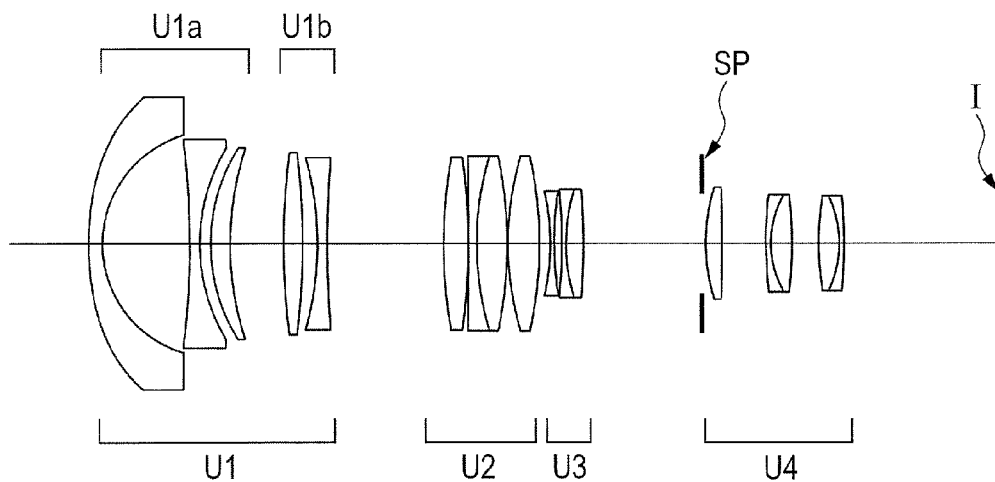


FIG. 12A

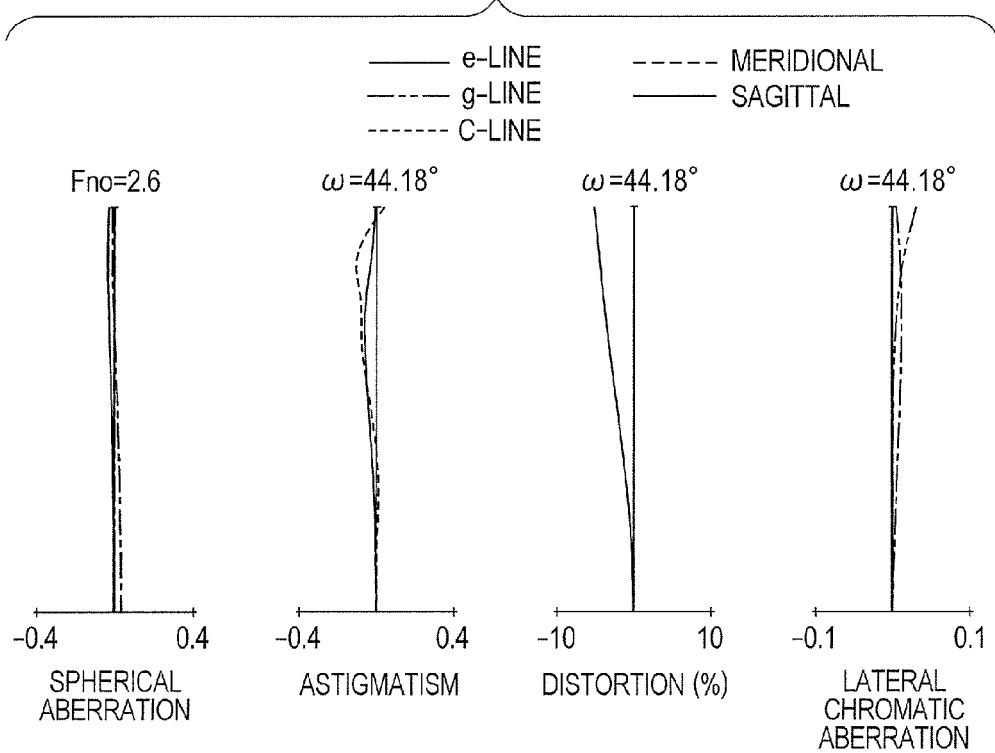


FIG. 12B

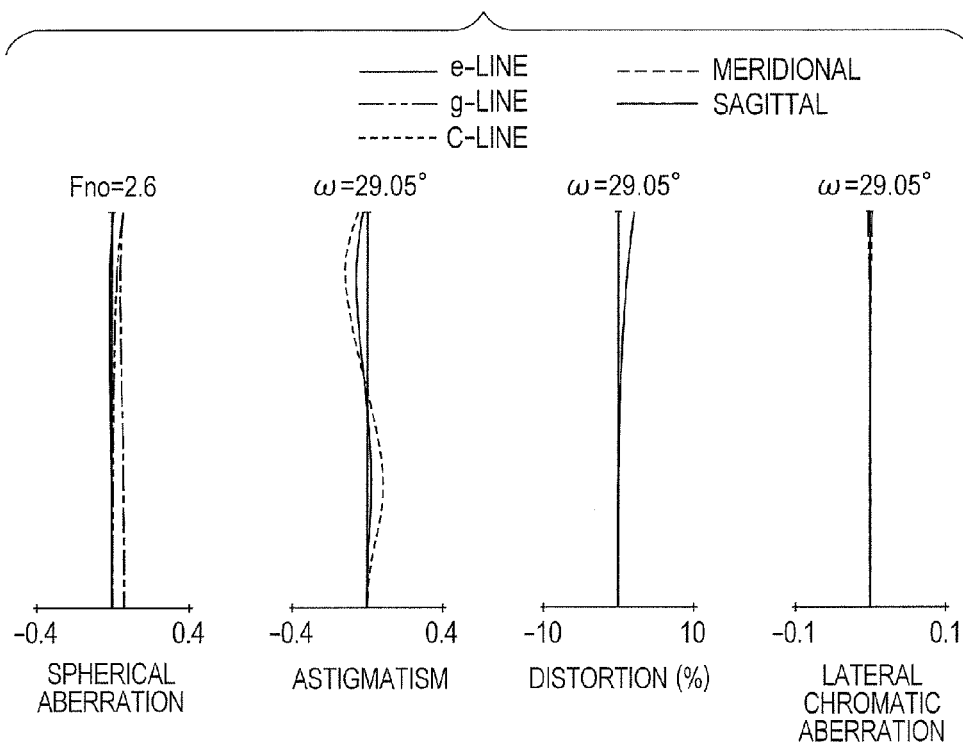


FIG. 12C

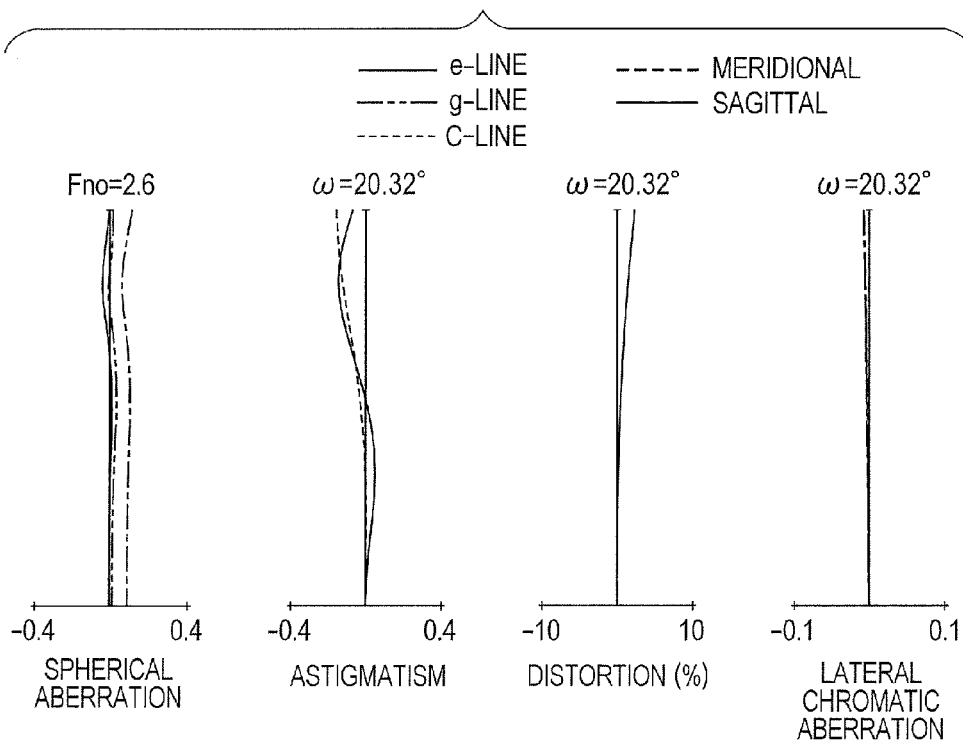


FIG. 13A

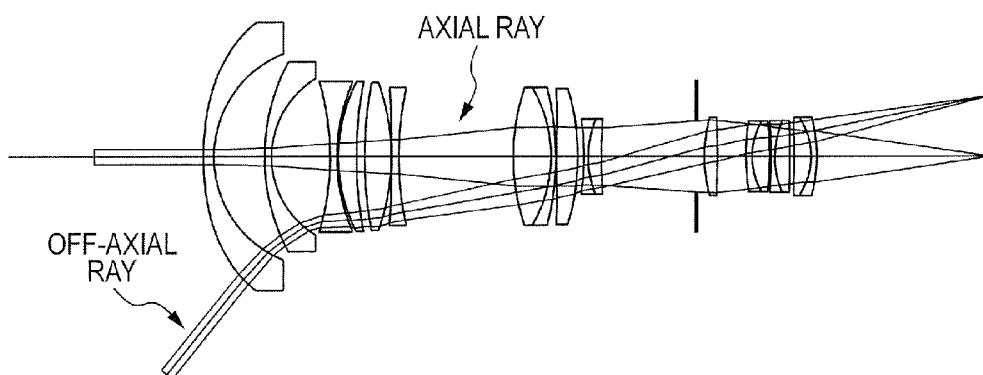


FIG. 13B

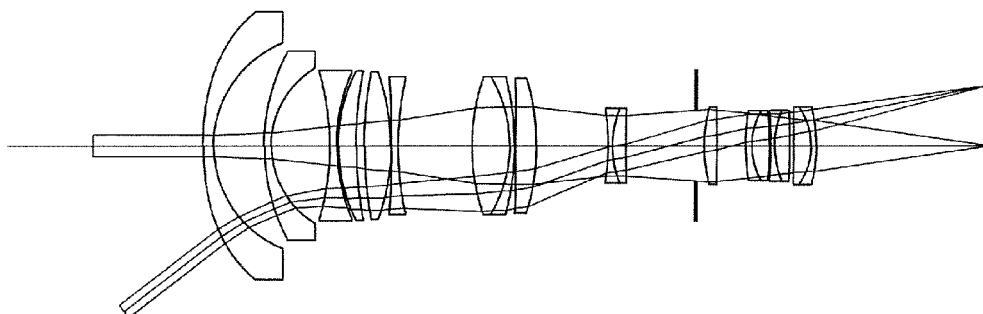


FIG. 13C

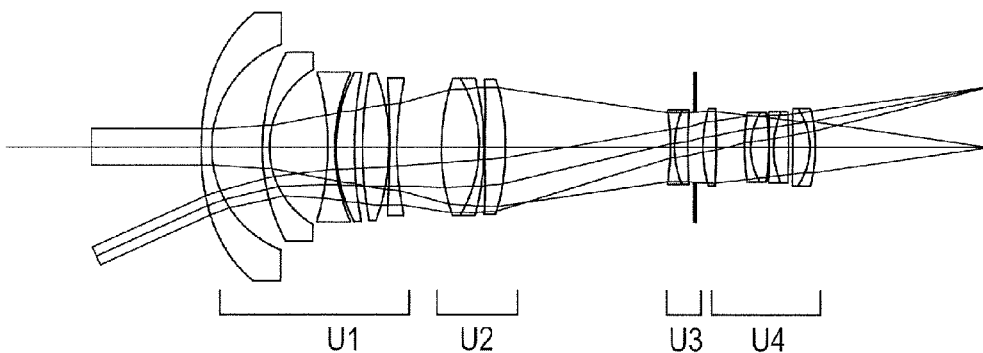


FIG. 14

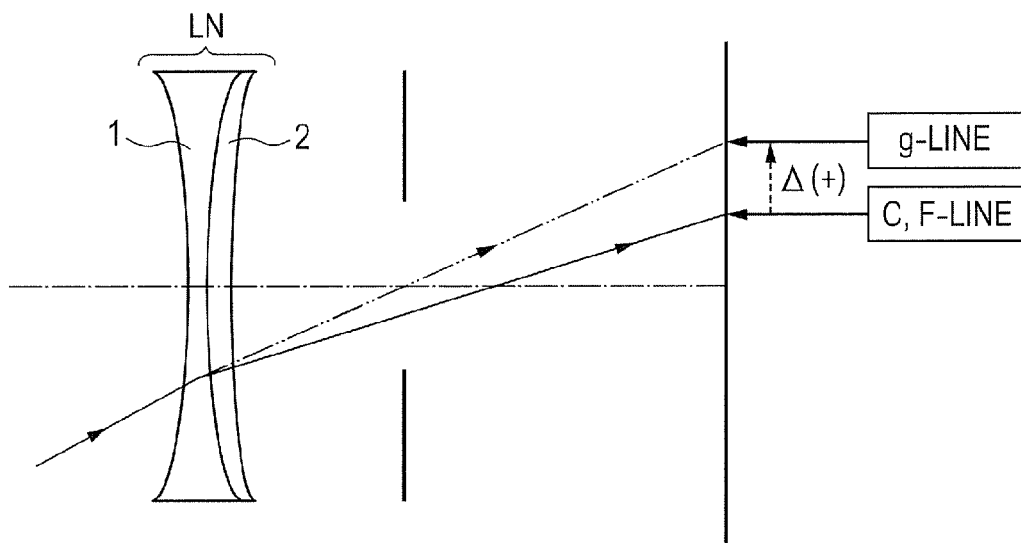


FIG. 15

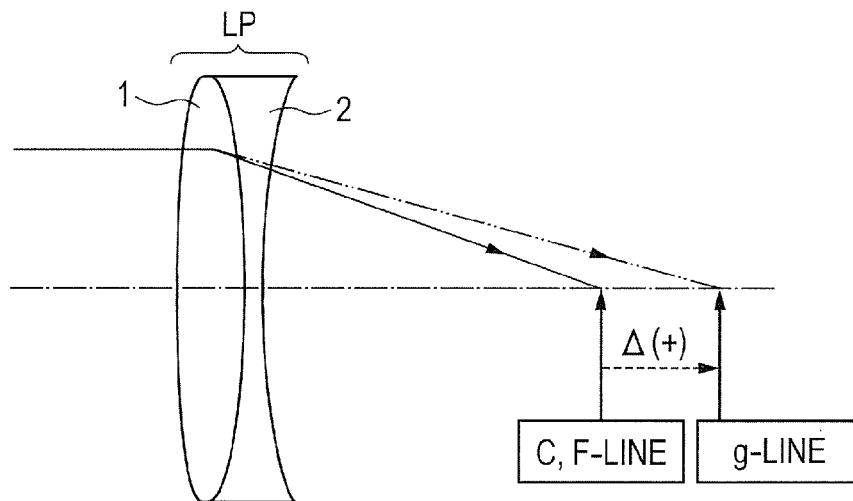
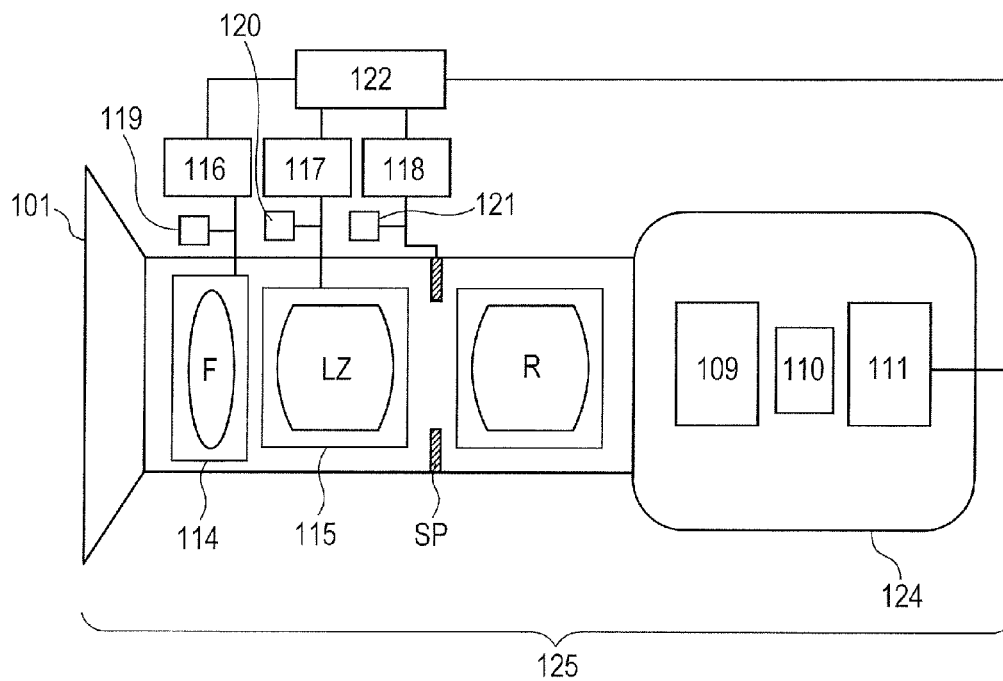


FIG. 16





# ZOOM LENS AND IMAGE PICKUP APPARATUS HAVING THE SAME

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a zoom lens, and an image pickup apparatus having the same, and particularly relates to a zoom lens which is suitable for a broadcasting television camera, a cinema camera, a video camera, a digital still camera, a silver-halide film camera and the like.

### 2. Description of the Related Art

In recent years, an image pickup apparatus such as a television camera, a cinema camera, a photographic camera and a video camera has been desired to be provided with a zoom lens which has a reduced size and weight, a wide angle of view and a high optical performance. An image pickup device such as CCD or CMOS which is used in a television/cinema camera as a moving image photographing system for professionals, in particular, has an almost even resolving power over the whole imaging range. Owing to this, the zoom lens to be used with such a device is required to have an almost even resolving power from the center of a screen to the periphery of the screen. In addition, reduction in size and weight is also required for a photographic style in which mobility and operability are regarded as important.

On the other hand, a wide angle lens having a short focal length at a wide angle end allows for photography over a wide range and enhanced perspective. Users who desire to use the photographic effect strongly demand a zoom lens that has a wider angle of view, a further reduced size and weight and a higher optical performance.

A negative-lead type of four-unit zoom lens is known as a wide-angle zoom lens, which has a lens unit having a negative refractive power arranged on the side closest to the object, and includes four lens units as a whole.

For instance, Japanese Patent Application Laid-Open No. H05-297276 discloses a four-unit zoom lens which has an F-number of approximately 2.0 at a wide angle end, an angle of view of approximately 60 degrees to 65 degrees at a wide angle end, an angle of view of approximately 14 degrees to 17 degrees at a telephoto end, and a zoom ratio of approximately 3.8. In addition, Japanese Patent Application Laid-Open No. H04-051006 discloses a four-unit zoom lens which has an F-number of approximately 1.5 to 2.2 at a wide angle end, an angle of view of approximately 50 degrees to 60 degrees at a wide angle end, an angle of view of approximately 8 degrees to 11 degrees at a telephoto end, and a zoom ratio of approximately 6. Japanese Patent Application Laid-Open No. S63-281113 discloses a four-unit zoom lens which has an F-number of approximately 1.8 at a wide angle end, an angle of view of approximately 80 degrees at a wide angle end, an angle of view of approximately 24 degrees at a telephoto end, and a zoom ratio of approximately 3.9. Any zoom lens includes, in order from the object side to the image side: a first lens unit having a negative refractive power; a second lens unit having a positive refractive power; a third lens unit having a negative refractive power; and a fourth lens unit having a positive refractive power.

However, in the zoom lenses which are disclosed in Japanese Patent Application Laid-Open No. H05-297276, Japanese Patent Application Laid-Open No. H04-051006 and Japanese Patent Application Laid-Open No. S63-281113, the refractive power and the lens configuration of each of the lens units are disadvantageous for further widening of the angle of view, and it becomes difficult to suppress the enlargement of a lens diameter resulting from the widening of the angle of

view. When the angle of view at the wide angle end exceeds 80 degrees, in particular, the lens diameter tends to be remarkably enlarged.

## SUMMARY OF THE INVENTION

An object of the present invention is to provide a zoom lens which has a wide angle of view, a reduced size and weight, and a high optical performance over a full zoom range, by appropriately setting the refractive power and the lens configuration of each lens unit, shares of aberration correction, and the like. Specifically, the object is to provide a zoom lens which has an angle of view of approximately 80 to 120 degrees at a wide angle end, an angle of view of approximately 25 degrees to 100 degrees at a telephoto end and a zoom ratio of approximately 1.5 to 4, and has a reduced size and weight and a high optical performance.

In order to achieve the above described objects, a zoom lens according to the present invention includes, in order from an object side to an image side: a first lens unit having a negative refractive power which does not move for zooming; a second lens unit having a positive refractive power which moves during the zooming; a third lens unit having a negative refractive power which moves during the zooming; and a fourth lens unit having a positive refractive power, wherein the following expressions are satisfied:

$$-0.80 < f1/f2 < -0.25,$$

$$-1.2 < f2/f3 < -0.4, \text{ and}$$

$$0.5 < |m2/m3| < 3.0,$$

where f1 represents a focal length of the first lens unit, f2 represents a focal length of the second lens unit, f3 represents a focal length of the third lens unit, m2 represents a moving amount of the second lens unit during the zooming from a wide angle end to a telephoto end, and m3 represents a moving amount of the third lens unit during the zooming from the wide angle end to the telephoto end.

The zoom lens having the wide angle of view, the reduced size and weight and the high optical performance over the full zooming range is achieved by appropriately setting the refractive power and the lens configuration of each lens unit, the sharing of aberration correction, and the like.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a sectional view of lenses when a zoom lens is set at a wide angle end and focuses on infinity, in Numeric Embodiment 1.

FIG. 2A illustrates views of aberration when the zoom lens is set at the wide angle end and focuses on infinity, in Numeric Embodiment 1.

FIG. 2B illustrates views of aberration when the zoom lens is set at the middle of the zoom and focuses on infinity, in Numeric Embodiment 1.

FIG. 2C illustrates views of aberration when the zoom lens is set at a telephoto end and focuses on infinity, in Numeric Embodiment 1.

FIG. 3 illustrates a sectional view of lenses when a zoom lens is set at a wide angle end and focuses on infinity, in Numeric Embodiment 2.

FIG. 4A illustrates views of aberration when the zoom lens is set at the wide angle end and focuses on infinity, in Numeric Embodiment 2.

FIG. 4B illustrates views of aberration when the zoom lens is set at the middle of the zoom and focuses on infinity, in Numeric Embodiment 2.

FIG. 4C illustrates views of aberration when the zoom lens is set at a telephoto end and focuses on infinity, in Numeric Embodiment 2.

FIG. 5 illustrates a sectional view of lenses when a zoom lens is set at a wide angle end and focuses on infinity, in Numeric Embodiment 3.

FIG. 6A illustrates views of aberration when the zoom lens is set at the wide angle end and focuses on infinity, in Numeric Embodiment 3.

FIG. 6B illustrates views of aberration when the zoom lens is set at the middle of the zoom and focuses on infinity, in Numeric Embodiment 3.

FIG. 6C illustrates views of aberration when the zoom lens is set at the telephoto end (c) and focuses on infinity, in Numeric Embodiment 3.

FIG. 7 illustrates a sectional view of lenses when a zoom lens is set at a wide angle end and focuses on infinity, in Numeric Embodiment 4.

FIG. 8A illustrates views of aberration when the zoom lens is set at the wide angle end and focuses on infinity, in Numeric Embodiment 4.

FIG. 8B illustrates views of aberration when the zoom lens is set at the middle of the zoom and focuses on infinity, in Numeric Embodiment 4.

FIG. 8C illustrates views of aberration when the zoom lens is set at a telephoto end and focuses on infinity, in Numeric Embodiment 4.

FIG. 9 illustrates a sectional view of lenses when a zoom lens is set at a wide angle end and focuses on infinity, in Numeric Embodiment 5.

FIG. 10A illustrates views of aberration when the zoom lens is set at the wide angle end and focuses on infinity, in Numeric Embodiment 5.

FIG. 10B illustrates views of aberration when the zoom lens is set at the middle of the zoom and focuses on infinity, in Numeric Embodiment 5.

FIG. 10C illustrates views of aberration when the zoom lens is set at a telephoto end and focuses on infinity, in Numeric Embodiment 5.

FIG. 11 illustrates a sectional view of lenses when a zoom lens is set at a wide angle end and focuses on infinity, in Numeric Embodiment 6.

FIG. 12A illustrates views of aberration at the time when the zoom lens is set in the wide angle end and focuses on infinity, in Numeric Embodiment 6.

FIG. 12B illustrates views of aberration at the time when the zoom lens is set in the middle of the zoom and focuses on infinity, in Numeric Embodiment 6.

FIG. 12C illustrates views of aberration at the time when the zoom lens is set in a telephoto end and focuses on infinity, in Numeric Embodiment 6.

FIG. 13A illustrates a view of a light path when the zoom lens is set at the wide angle end, in Numeric Embodiment 1.

FIG. 13B is a view of a light path when the zoom lens is set at the middle of the zoom, in Numeric Embodiment 1.

FIG. 13C is a view of a light path when the zoom lens is set at the telephoto end, in Numeric Embodiment 1.

FIG. 14 illustrates a schematic view concerning chromatic aberration correction and residual secondary spectrum of two colors, in lateral chromatic aberration of a negative lens unit.

FIG. 15 illustrates a schematic view concerning chromatic aberration correction and residual secondary spectrum of two colors, in axial chromatic aberration of a positive lens unit.

FIG. 16 illustrates a schematic view of an essential part of an image pickup apparatus according to the present invention.

#### DESCRIPTION OF THE EMBODIMENTS

Preferred embodiments of the present invention will now be described in detail in accordance with the accompanying drawings.

Firstly, the features of the zoom lens according to the present invention will be described below with reference to each conditional expression. In order to achieve a wide angle of view, a reduced size and weight, and a high optical performance over a full zooming range, the zoom lens according to the present invention specifies a ratio between focal lengths of a first lens unit and a second lens unit, a ratio between focal lengths of a second lens unit and a third lens unit, and a ratio between moving amounts of the second lens unit and the third lens unit when zooming from a wide angle end to a telephoto end. The moving amount is a difference between positions before and after the movement on an optical axis. When a lens unit is moved to a position closer to the image (telephoto end) than the position before the movement (wide angle end), the position after the movement is determined to be positive.

The zoom lens according to the present invention includes, in order from the object side to the image side: a first lens unit having a negative refractive power which does not move for zooming; a second lens unit having a positive refractive power which moves during zooming; a third lens unit having a negative refractive power which moves during zooming; and a fourth lens unit having a positive refractive power. Furthermore, when the focal length of the first lens unit is represented by  $f_1$ , the focal length of the second lens unit is represented by  $f_2$ , the focal length of the third lens unit is represented by  $f_3$ , the moving amount of the second lens unit during zooming from a wide angle end to a telephoto end is represented by  $m_2$  and the moving amount of the third lens unit during zooming is represented by  $m_3$ , the  $f_1$ , the  $f_2$ , the  $f_3$ , the  $m_2$  and the  $m_3$  satisfy the expressions of:

$$-0.80 < f_1/f_2 < -0.25 \quad (1)$$

$$-1.2 < f_2/f_3 < -0.4 \quad (2)$$

$$0.5 < |m_2/m_3| < 3.0 \quad (3).$$

An optical function of the zoom lens in the present invention will be described below, which includes: a first lens unit having a negative refractive power which does not move for zooming; a second lens unit having a positive refractive power which moves during zooming; a third lens unit having a negative refractive power which moves during zooming; and a fourth lens unit having a positive refractive power.

FIGS. 13A, 13B and 13C illustrate views of light paths when the zoom lens is set the wide angle end, the middle of the zoom and the telephoto end respectively, in Exemplary Embodiment 1 according to the present invention. U1 to U4 represent the first lens unit to the fourth lens unit respectively. As is understood from in FIGS. 13A, 13B and 13C, in Exemplary Embodiment 1 according to the present invention, the first lens unit and the second lens unit form such trajectory that the first lens unit and the second lens unit are separated from each other in the wide angle end, and the first lens unit and the second lens unit become close to each other in the telephoto end. The zoom lens in Exemplary Embodiment 1 can arrange the first lens unit having the negative refractive power and the second lens unit having the positive refractive power so as to be separated from each other when having been set at the wide angle end, accordingly can reduce the absolute

5

value of the lateral magnification of the second lens unit when having been set at the wide angle end, and can push the entrance pupil to the object side. Because of this, the zoom lens is configured so as to be advantageous for achieving both widening of an angle of view and a reduced size and weight. Furthermore, when the  $f_1$ , the  $f_2$ , the  $f_3$ , the  $m_2$  and the  $m_3$  satisfy the previously described expressions (1) to (3), the zoom lens can effectively achieve a wide angle of view, a reduced size and weight, and a high optical performance over a full zooming range.

Expression (1) specifies a ratio between a focal length of the first lens unit and a focal length of the second lens unit. When the  $f_1$  and the  $f_2$  satisfy the Expression (1), the zoom lens achieves the widening of an angle of view and the correction of aberration variation at the same time. The focal length of the zoom lens becomes a value obtained by multiplying the focal length of the first lens unit by a lateral magnification of the second lens unit to the fourth lens unit, and accordingly, in order to achieve the widening of the angle of view, it is necessary to appropriately set the focal length of the first lens unit. If the condition of the upper limit of the Expression (1) is not satisfied, the refractive power of the first lens unit becomes strong, and it becomes difficult to correct the aberration variation due to zooming and the aberration variation due to focusing. If the condition of the lower limit of the Expression (1) is not satisfied, the first lens unit lacks in its refractive power, and accordingly it becomes difficult to widen the angle of view and reduce the size and weight at the same time. It is desirable that the Expression (1) can be set further in the following way:

$$-0.70 < f_1/f_2 < -0.35 \quad (1a).$$

In addition, Expression (2) specifies a ratio between a focal length of the second lens unit and a focal length of the third lens unit. When the  $f_2$  and the  $f_3$  satisfy the Expression (2), the zoom lens can efficiently achieve the reduction in the size and weight and a high optical performance. If the upper limit of the Expression (2) is not satisfied, the refractive power of the second lens unit becomes strong, and accordingly the aberration variation due to zooming, in particular, variations of spherical aberration and field curvature increase, and it becomes difficult to achieve an adequate optical performance in the whole zooming region. If the condition of the lower limit of the Expression (2) is not satisfied, the refractive power of the second lens unit becomes weak, and accordingly an image point (=object point of third lens unit) of the second lens unit is arranged in the image side. Because of this, the moving amount of the third lens unit due to zooming increases, and it becomes difficult to reduce the size and weight. It is desirable that the Expression (2) can be set further in the following way:

$$-1.1 < f_2/f_3 < -0.5 \quad (2a).$$

Expression (3) specifies a ratio between a moving amount of the second lens unit and a moving amount of the third lens unit when the zoom lens moves from a wide angle end to a telephoto end. When the  $m_2$  and the  $m_3$  satisfy the Expression (3), the zoom lens can achieve the reduction in the size and weight and a high optical performance at the same time. Here, pay attention to the height of the light beam of an on-axis light beam in the views of the light path in FIGS. 13A, 13B and 13C, and it is understood that the variation of the height of the light beam occurring when the second lens unit has moved from the wide angle end to the telephoto end is large compared to the variation in the third lens unit. Because of this, it is desirable for adequately correcting the aberration to reduce the moving amount of the second lens unit during zooming. If

6

the upper limit of the Expression (3) is not satisfied, the moving amount of the second lens unit during zooming increases, and because of the above described reason, it becomes difficult to achieve the adequate optical performance in the whole zooming region. If the condition of the lower limit of Expression (3) is not satisfied, the moving amount of the third lens unit due to zooming increases, and it becomes difficult to reduce the size and weight. It is desirable that the Expression (3) can be set further in the following way:

$$0.65 < |m_2/m_3| < 2.70 \quad (3a)$$

Another aspect of the zoom lens according to the present invention specifies the configuration and the focusing of the first lens unit. The first lens unit includes a first sub lens unit having a negative refractive power which does not move for focusing, and a second sub lens unit which moves during focusing. When the focal length of the first sub lens unit is represented by  $f_{11}$ , and the focal length of the second sub lens unit is represented by  $f_{12}$ , the  $f_{11}$  and the  $f_{12}$  satisfy the expression of:

$$0.005 < |f_{11}/f_{12}| < 0.150 \quad (4).$$

Expression (4) is specified so as to suppress the moving amount of the second sub lens unit during focusing and achieve a high optical performance. If the condition of the upper limit of the Expression (4) is not satisfied, the refractive power of the first sub lens unit becomes weak, the moving amount of the second sub lens unit during focusing increases, which is disadvantageous for the reduction in the size and weight of the zoom lens. If the condition of the lower limit of the Expression (4) is not satisfied, the refractive power of the first sub lens unit becomes strong, and it becomes difficult to correct the aberration variation due to focusing. In addition, if the number of the lenses which constitute the first sub lens unit has been increased so as to achieve the adequate optical performance, it becomes difficult to reduce the size and weight of the zoom lens. It is desirable that the Expression (4) can be set further in the following way:

$$0.01 < |f_{11}/f_{12}| < 0.08 \quad (4a).$$

Another aspect of the zoom lens according to the present invention specifies that the zoom lens focuses with the fourth lens unit or a lens unit of a part of the fourth lens unit. It becomes advantageous for the followability during focusing and the downsizing of a driving mechanism to perform focusing with the fourth lens unit having a small lens diameter and a light weight or with the lens unit of a part of the fourth lens unit.

Another aspect of the zoom lens according to the present invention specifies the configuration of a front sub lens unit which does not move for the focusing out of the lenses that constitute the first lens unit. The front sub lens unit includes one or more convex lenses and two or more concave lenses, wherein a lens closest to the object in the front sub lens unit is a concave lens and a lens closest to the image in the front sub lens unit is a convex lens. When the front sub lens unit has a lens having a negative refractive power arranged on the side closest to the object in the front sub lens unit, and a lens having a positive refractive power arranged on the side closest to the image in the front sub lens unit, the first lens unit is configured so as to facilitate the image side principal point of the first lens unit to be set in the object side, and become advantageous for the widening of the angle of view.

Another aspect of the zoom lens according to the present invention specifies a partial dispersion ratio of the optical material which is used in the front sub lens unit. When the average values of the Abbe number and the partial dispersion

ratio of the convex lenses which constitute the front sub lens unit are represented by  $v1p$  and  $\theta1p$  respectively, and the average values of the Abbe number and the partial dispersion ratio of the concave lenses which constitute the front sub lens unit are represented by  $v1n$  and  $\theta1n$  respectively, the  $v1p$ , the  $\theta1p$ , the  $v1n$  and the  $\theta1n$  satisfy the expression of:

$$-2.50 \times 10^{-3} < (\theta1p - \theta1n) / (v1p - v1n) < -1.30 \times 10^{-3} \quad (5).$$

Here, the Abbe number and the partial dispersion ratio of the material of the optical element (lens) which is used in the present invention are as follows. When the refractive indices in the g-line (435.8 nm), the F-line (486.1 nm), the d-line (587.6 nm) and the C-line (656.3 nm) of Fraunhofer lines shall be represented by  $N_g$ ,  $N_F$ ,  $N_d$  and  $N_C$  respectively, the Abbe number  $vd$  and the partial dispersion ratio  $\theta_gF$  concerning the g-line and the F-line are as follows.

$$vd = (N_d - 1) / (N_F - N_C) \quad (a)$$

$$\theta_gF = (N_g - N_F) / (N_F - N_C) \quad (b)$$

In existing optical materials, the partial dispersion ratio  $\theta_gF$  exists in a narrow range of the Abbe number  $vd$ . In addition, the optical materials have such a tendency that as the Abbe number  $vd$  is smaller, the partial dispersion ratio  $\theta_gF$  is larger, and as the Abbe number  $vd$  is larger, the refractive index is lower. Here, a correction condition for the chromatic aberration of a thin-wall close-contact system which is formed of two lenses **1** and **2** having refractive powers  $\phi1$  and  $\phi2$  and Abbe numbers  $v1$  and  $v2$  respectively, is expressed by:

$$\phi1/v1 + \phi2/v2 = E \quad (c).$$

Here, the combined refractive index  $\phi$  of the lenses **1** and **2** is expressed by:

$$\phi = \phi1 + \phi2 \quad (d).$$

In the Expression (c), if  $E=0$  is satisfied, imaging positions of the C-line and the F-line coincide with each other in the chromatic aberration. At this time,  $\phi1$  and  $\phi2$  are expressed by the following expressions.

$$\phi1 = \phi \times v1 / (v1 - v2) \quad (e)$$

$$\phi2 = \phi \times v2 / (v1 - v2) \quad (f)$$

FIG. 14 is a schematic view concerning chromatic aberration correction and residual secondary spectrum of two colors, in lateral chromatic aberration due to a lens unit LN which exists in between an object surface and an aperture stop and has a negative refractive power. In the chromatic aberration correction of the negative lens unit LN in FIG. 14, a material having a large Abbe number  $v1$  is used for a negative lens **1**, and a material having a small Abbe number  $v2$  is used for a positive lens **2**. Accordingly, the negative lens **1** has a small partial dispersion ratio  $\theta1$ , and the positive lens **2** has a large partial dispersion ratio  $\theta2$ . When the lateral chromatic aberration is corrected in the C-line and the F-line, the imaging point of the g-line deviates toward a direction distant from the optical axis. When the amount of deviation of the lateral chromatic aberration of the g-line from that of the C-line and the F-line is defined as the amount  $\Delta Y$  of a secondary spectrum,  $\Delta Y$  is expressed by the expression of:

$$\Delta Y = (1/\phi) \times (\theta1 - \theta2) / (v1 - v2) \quad (g).$$

In order to adequately correct the secondary spectrum of the lateral chromatic aberration in the wide angle end, it is necessary to adjust the amount of the secondary spectrum to be generated in the front sub lens unit in which the secondary spectrum of the lateral chromatic aberration is remarkably generated. The front sub lens unit has a negative refractive

power, and in order to adequately correct the secondary spectrum of the lateral chromatic aberration in the wide angle end, it is necessary to select such a glass material as to reduce the amount  $\Delta Y$  of the secondary spectrum which is generated in the front sub lens unit.

The condition of the Expression (5) is specified in order to achieve the correction of the lateral chromatic aberration in the wide angle end and a high optical performance. If the condition of the upper limit of Expression (5) is not satisfied, the result is advantageous for the correction of the secondary spectrum of the lateral chromatic aberration in the wide angle end. However, the refractive index of the concave lens which constitutes the front sub lens unit is lowered, and the radius of curvature of the concave lens which constitutes the front sub lens unit decreases. As a result, the high order aberration of the field curvature and the coma increases, and it becomes difficult to achieve the adequate optical performance. If the condition of the lower limit of the Expression (5) is not satisfied, the secondary spectrum of the lateral chromatic aberration in the wide angle end increases, and it becomes difficult to adequately correct the chromatic aberration in the wide angle end. It is desirable that the Expression (5) can be set further in the following way:

$$-2.35 \times 10^{-3} < (\theta1p - \theta1n) / (v1p - v1n) < -1.45 \times 10^{-3} \quad (5a).$$

Another aspect of the zoom lens according to the present invention specifies the configuration of the second lens unit and a partial dispersion ratio of an optical material which is used in the second lens unit. The second lens unit includes two or more convex lenses and one or more concave lenses, wherein when the average values of the Abbe number and the partial dispersion ratio of the convex lenses which constitute the second lens unit are represented by  $v2p$  and  $\theta2p$  respectively, and the average values of the Abbe number and the partial dispersion ratio of the concave lenses are represented by  $v2n$  and  $\theta2n$  respectively, the  $v2p$ , the  $\theta2p$ , the  $v2n$  and the  $\theta2n$  satisfy the expression of:

$$-2.30 \times 10^{-3} < (\theta2p - \theta2n) / (v2p - v2n) < -1.20 \times 10^{-3} \quad (6).$$

FIG. 15 illustrates a schematic view concerning chromatic aberration correction and residual secondary spectrum of two colors, in axial chromatic aberration of a lens unit LP having a positive refractive power. In FIG. 15, a material having a large Abbe number  $v1$  is used for a positive lens **1**, and a material having a small Abbe number  $v2$  is used for a negative lens **2**. Accordingly, the partial dispersion ratio  $\theta1$  of the positive lens **1** becomes small, and the partial dispersion ratio  $\theta2$  of the negative lens **2** becomes large. Consequently, when the axial chromatic aberration has been corrected in the C-line and the F-line, the imaging point of the g-line deviates to the image side. In the case where a luminous flux has been incident on the lens system from the infinite object distance, when the amount of deviation of the axial chromatic aberration of the g-line from that of the C-line and the F-line is defined as the amount  $\Delta S$  of the secondary spectrum,  $\Delta S$  is expressed by:

$$\Delta S = -(1/\phi) \times (\theta1 - \theta2) / (v1 - v2) \quad (h).$$

In order to adequately correct the secondary spectrum of the axial chromatic aberration in the telephoto end, it is necessary to adjust the amount of the secondary spectrum to be generated in the second lens unit in which the secondary spectrum is remarkably generated. The second lens unit has a positive refractive power, and in order to adequately correct the secondary spectrum of the axial chromatic aberration in the telephoto end, it is necessary to select such a glass material as

to reduce the amount  $\Delta S$  of the secondary spectrum which is generated in the second lens unit.

The condition of the Expression (6) is specified in order to achieve the correction of the axial chromatic aberration in the telephoto end and a high optical performance. If the condition of the upper limit of the Expression (6) is not satisfied, the result is advantageous for the correction of the secondary spectrum of the axial chromatic aberration in the telephoto end. However, the refractive index of the convex lens which constitutes the second lens unit is lowered, and the radius of curvature of the convex lens which constitutes the second lens unit decreases. As a result, the high order aberration of the spherical aberration in the telephoto end increases, and it becomes difficult to achieve the adequate optical performance. On the contrary, if the condition of the lower limit of the Expression (6) is not satisfied, the secondary spectrum of the axial chromatic aberration in the telephoto end increases, and it becomes difficult to adequately correct the chromatic aberration in the telephoto end. It is desirable that the Expression (6) can be set further in the following way.

$$-2.15 \times 10^{-3} < (0.2p - 0.2n) / (v2p - v2n) < -1.35 \times 10^{-3} \quad (6a)$$

The zoom lens of the present invention specifies that the second lens unit has a lens having an aspherical surface formed on at least one or more surfaces, as a further aspect. Pay attention to the height of the light beam of an on-axis light beam in the views of the light path in FIGS. 13A, 13B and 13C, and it is understood that a difference of the heights of the light beams in the second lens unit is large between the wide angle end and the telephoto end. Because of this, the lens having the aspherical surface formed thereon is adopted as the second lens unit. Thereby, the variation of the spherical aberration due to the zooming can be adequately corrected.

Furthermore, an image pickup apparatus according to the present invention has a zoom lens of each exemplary embodiment, and has an image pickup element that receives (photoelectrically converts) an optical image which has been formed by the zoom lens, and that has a predetermined effective imaging range.

The specific configuration of the zoom lens according to the present invention will be described below with reference to the features of the configurations of the lenses of Numeric Embodiments 1 to 6, which correspond to Exemplary Embodiments 1 to 6 respectively.

#### Exemplary Embodiment 1

FIG. 1 is a sectional view of lenses at the time when the zoom lens of Exemplary Embodiment 1 (Numeric Embodiment 1) according to the present invention is set in a wide angle end and focuses on infinity. FIG. 2A illustrates views of longitudinal aberration at the time when the zoom lens is set in the wide angle end in Numeric Embodiment 1; FIG. 2B illustrates views of longitudinal aberration at the time when the focal length is set at 18.75 mm in Numeric Embodiment 1; and FIG. 2C illustrates views of longitudinal aberration at the time when the zoom lens is set in the telephoto end in Numeric Embodiment 1. Any view of the aberration is a view of the longitudinal aberration at the time when the zoom lens focuses on infinity. In addition, the value of the focal length is such a value that a value of the focal length in the numeric embodiments which will be described later is expressed by a mm unit. The above description is the same in all of the following numeric embodiments.

In FIG. 1, the zoom lens has, in order from the object side to the image side, a first lens unit U1 for focusing, which has a negative refractive power. The zoom lens has further a

second lens unit U2 for zooming, which moves to the object side during zooming from the wide angle end to the telephoto end and has a positive refractive power. The zoom lens has still a third lens unit U3 which moves non-linearly on the optical axis in synchronization with the movement of the second lens unit U2, corrects the variation of the image plane due to the zooming and has a negative refractive power. The zoom lens has still further a fourth lens unit U4 which does not move for zooming, performs an imaging operation and has a positive refractive power.

The second lens unit U2 and the third lens unit U3 constitute a variator. An aperture stop SP is arranged in the object side of the fourth lens unit U4. An image plane I corresponds to an imaging plane of an image pickup element (photoelectric conversion element) or the like, which receives an optical image formed by the zoom lens and converts the optical image to an electric signal, when being used as an image pickup optical system of a broadcasting television camera, a video camera and a digital still camera. When being used as an image pickup optical system of a camera for a film, the image plane corresponds to a film surface which senses light of an image formed by the zoom lens.

In the view of the longitudinal aberration, a straight line, a chain double-dashed line and an alternate long and short dashed line in the spherical aberration are the e-line, the g-line and the C-line respectively. The dotted lines and the solid lines in the astigmatism are a meridional image plane and a sagittal image plane respectively; and a chain double-dashed line and an alternate long and short dashed line in the lateral chromatic aberration are the g-line and the C-line respectively. A half angle of view  $w$  is shown, and an F-number  $F_{no}$  is shown. In the view of the longitudinal aberration, the spherical aberration is drawn with a scale of 0.4 mm, the astigmatism is drawn with a scale of 0.4 mm, the distortion is drawn with a scale of 10%, and the lateral chromatic aberration is drawn with a scale of 0.1 mm. Incidentally, in each of the following exemplary embodiments, the wide angle end and the telephoto end mean zoom positions shown when the zoom lens is positioned in both ends in such a range that the second unit U2 for zooming can move on the optical axis with respect to the mechanism respectively.

Next, the first lens unit U1 in the present exemplary embodiment will be described. The first lens unit U1 corresponds to a first surface to a 12th surface. The first lens unit U1 includes: a first sub lens unit U1a having a negative refractive power which does not move for focusing; and a second sub lens unit U1b having a positive refractive power which moves to the image side when the focus is moved to an extremely close side from an infinity side. The first sub lens unit U1a includes, in order from the object side to the image side: a meniscus concave lens G1 which is convex toward the object side; a meniscus concave lens G2 which is convex toward the object side; a biconcave lens G3; and a meniscus convex lens G4 which is concave toward the image side. In addition, the first surface has an aspherical surface shape, and mainly corrects distortion aberration and field curvature in the wide angle side. The second sub lens unit U1b includes: a biconvex lens G5; and a biconcave lens G6. The second lens unit U2 includes: a cemented lens of a biconvex lens and a meniscus concave lens which is convex toward the image side; and a biconvex lens. In addition, a 16th surface and a 17th surface have an aspherical surface shape, and mainly correct the variation of the spherical aberration due to the zooming. The third lens unit U3 includes a cemented lens of a biconcave lens and a meniscus convex lens which is concave toward the image side. The fourth lens unit U4 includes a convex lens and a concave lens, and is formed of seven lenses as a whole.

## 11

Numeric Embodiment 1 corresponding to the above described Exemplary Embodiment 1 will be described below. Not only in Numeric Embodiment 1 but also in all of the numeric embodiments, an order  $i$  of surfaces (optical surface) from the object side, a radius of curvature  $r_i$  of the  $i$ -th surface from the object side, and a space (on optical axis)  $d_i$  between the  $i$ -th surface from the object side and the  $(i+1)$ -th surface from the object side are shown. In addition, a refractive index  $n_{di}$ , an Abbe number  $v_{di}$  and a partial dispersion ratio  $\theta_{gFi}$  each of a medium (optical member) between the  $i$ -th surface and the  $(i+1)$ -th surface are shown; and an air-equivalent back-focus BF is shown. When an optical axis direction is determined to be an X-axis, a direction perpendicular to the optical axis is determined to be an H-axis, a traveling direction of light is determined to be positive,  $R$  represents a paraxial radius of curvature,  $k$  represents a conic constant, and A4, A6, A8, A10 and A12 each represent an aspherical coefficient, an aspherical surface shape is expressed by the following expression. In addition, “e-Z” means “ $\times 10^{-Z}$ ”.

$$X = \frac{H^2/R}{1 + \sqrt{1 - (1+k)(H/R)^2}} + A4H^4 + A6H^6 + A8H^8 + A10H^{10} + A12H^{12} \quad [\text{Expression 1}]$$

The values of the present exemplary embodiment, which correspond to each conditional expression, are shown in Table 1. The present exemplary embodiment satisfies the Expressions (1) to (6), and achieves a photographing angle of view (angle of view) of  $102.4^\circ$  in the wide angle end to widen the angle of view. The present exemplary embodiment also achieves a zoom lens which has various aberrations adequately corrected in the whole zooming region and has a high optical performance. However, it is indispensable for the zoom lens according to the present invention to satisfy the Expressions (1), (2) and (3), but it is acceptable not to satisfy the Expressions (4) to (6). However, if the zoom lens satisfies at least one of the Expressions (4) to (6), the zoom lens can show a more adequate effect. The above description is similar also in other exemplary embodiments.

FIG. 16 illustrates a schematic view of an image pickup apparatus (television camera system) which uses a zoom lens of each exemplary embodiment as a photographing optical system. In FIG. 16, a zoom lens 101 is any of zoom lenses in Exemplary Embodiments 1 to 6. A camera 124 is shown. The zoom lens 101 is structured so as to be removable from the camera 124. An image pickup apparatus 125 includes the camera 124 and the zoom lens 101 which is mounted on the camera. The zoom lens 101 has a first lens unit F, a zooming portion LZ, and a fourth lens unit R for imaging. The first lens unit F includes a lens unit for focusing. The zooming portion LZ includes: a second lens unit which moves on the optical axis for zooming; and a third lens unit which moves on the optical axis for correcting the variation of the image plane due to zooming. An aperture stop SP is shown. Driving mechanisms 114 and 115 include a helicoid and a cam, and drive the first lens unit F and the zooming portion LZ in the optical axis direction respectively. Motors (driving unit) 116 to 118 electrically drive the driving mechanisms 114 and 115 and the aperture stop SP. Detectors 119 to 121 include an encoder, a potentiometer and a photosensor, and detect positions of the first lens unit F and the zooming portion LZ on the optical axis, and the aperture stop diameter of the aperture stop SP. In the camera 124, a glass block 109 corresponds to an optical filter and a color separation optical system which are accom-

## 12

modated in the camera 124, and an image pickup element (photoelectric conversion element) 110 is a CCD sensor or a CMOS sensor, and receives (photoelectrically converts) a subject image (optical image) which has been formed by the zoom lens 101. In addition, CPUs 111 and 122 control various drivings of the camera 124 and the zoom lens 101.

Thus, the zoom lens according to the present invention is applied to a television camera, and thereby an image pickup apparatus having a high optical performance is achieved.

## Exemplary Embodiment 2

FIG. 3 illustrates a sectional view of lenses at the time when the zoom lens of Exemplary Embodiment 2 (Numeric Embodiment 2) according to the present invention is set in a wide angle end and focuses on infinity. FIG. 4A illustrates views of longitudinal aberration at the time when the zoom lens is set in the wide angle end in Numeric Embodiment 2; FIG. 4B illustrates views of longitudinal aberration at the time when the focal length is set at 26.88 mm in Numeric Embodiment 2; and FIG. 4C illustrates views of longitudinal aberration at the time when the zoom lens is set in a telephoto end in Numeric Embodiment 2. Any view of the aberration is a view of the longitudinal aberration at the time when the zoom lens focuses on infinity. In FIG. 3, the zoom lens has, in order from the object side to the image side, a first lens unit U1 for focusing, which has a negative refractive power. The zoom lens has further a second lens unit U2 for zooming, which moves to the object side during zooming from the wide angle end to the telephoto end and has a positive refractive power. The zoom lens has still a third lens unit U3 which moves non-linearly on the optical axis in synchronization with the movement of the second lens unit U2, corrects the variation of the image plane due to the zooming, and has a negative refractive power. The zoom lens has still further a fourth lens unit U4 which does not move for zooming, performs an imaging operation, and has a positive refractive power.

Next, the first lens unit U1 in the present exemplary embodiment will be described. The first lens unit U1 corresponds to a first surface to a tenth surface. The first lens unit U1 includes: a first sub lens unit U1a having a negative refractive power which does not move for focusing; and a second sub lens unit U1b having a positive refractive power which moves to the image side when the focus is moved to an extremely close side from an infinity side. The first sub lens unit U1a includes, in order from the object side to the image side: a meniscus concave lens G1 which is convex toward the object side; a biconcave lens G2; and a meniscus convex lens G3 which is concave toward the image side. In addition, the first surface has an aspherical surface shape, and mainly corrects distortion aberration and field curvature in the wide angle side. The second sub lens unit U1b includes: a biconvex lens G4; and a biconcave lens G5. The second lens unit U2 includes: a meniscus convex lens which is concave toward the object side; a cemented lens of a biconvex lens and a meniscus concave lens which is convex toward the image side; and a biconvex lens. In addition, a 16th surface and a 17th surface have an aspherical surface shape, and mainly correct the variation of the spherical aberration due to the zooming. The third lens unit U3 includes: a biconcave lens; and a cemented lens of a biconcave lens and a biconvex lens. The fourth lens unit U4 includes a convex lens and a concave lens, and is formed of six lenses as a whole. The values of the present exemplary embodiment, which correspond to each conditional expression, are shown in Table 1. The present exemplary embodiment satisfies the Expressions (1) to (6), and achieves a photographing angle of view (angle of view) of

88.4° in the wide angle end to widen the angle of view. The present exemplary embodiment also achieves the zoom lens which has various aberrations adequately corrected in the whole zooming region and has a high optical performance.

#### Exemplary Embodiment 3

FIG. 5 illustrates a sectional view of lenses at the time when a zoom lens of Exemplary Embodiment 3 (Numeric Embodiment 3) according to the present invention is set in a wide angle end and focuses on infinity. FIG. 6A illustrates views of longitudinal aberration at the time when the zoom lens is set in the wide angle end in Numeric Embodiment 3; FIG. 6B illustrates views of longitudinal aberration at the time when the focal length is set at 15.23 mm in Numeric Embodiment 3; and FIG. 6C illustrates views of longitudinal aberration at the time when the zoom lens is set in the telephoto end in Numeric Embodiment 3. Any view of the aberration is a view of the longitudinal aberration at the time when the zoom lens focuses on infinity.

In FIG. 5, the zoom lens has, in order from the object side to the image side, a first lens unit U1 for focusing, which has a negative refractive power. The zoom lens has further a second lens unit U2 for zooming, which moves to the object side during zooming from the wide angle end to the telephoto end and has a positive refractive power. The zoom lens has still a third lens unit U3 which moves non-linearly on the optical axis in synchronization with the movement of the second lens unit U2, corrects the variation of the image plane due to the zooming and has a negative refractive power. The zoom lens has still further a fourth lens unit U4 which does not move for zooming, performs an imaging operation, and has a positive refractive power.

Next, the first lens unit U1 in the present exemplary embodiment will be described. The first lens unit U1 corresponds to a first surface to a 12th surface. The first lens unit U1 includes: a first sub lens unit U1a having a negative refractive power which does not move for focusing; and a second sub lens unit U1b having a positive refractive power which moves to the image side when the focus is moved to an extremely close side from an infinity side. The first sub lens unit U1a includes, in order from the object side to the image side: a meniscus concave lens G1 which is convex toward the object side; a meniscus concave lens G2 which is convex toward the object side; a biconcave lens G3; and a meniscus convex lens G4 which is concave toward the image side. In addition, the first surface has an aspherical surface shape, and mainly corrects distortion aberration and field curvature in the wide angle side. The second sub lens unit U1b includes: a biconvex lens G5; and a biconcave lens G6. The second lens unit U2 includes: a cemented lens of a biconvex lens and a meniscus concave lens which is convex toward the image side; and a biconvex lens. In addition, a 16th surface and a 17th surface have an aspherical surface shape, and mainly correct the variation of the spherical aberration due to the zooming. The third lens unit U3 includes: a cemented lens of a biconcave lens and a meniscus convex lens which is concave toward the image side. The fourth lens unit U4 includes a convex lens and a concave lens, and is formed of seven lenses as a whole. The values of the present exemplary embodiment, which correspond to each conditional expression, are shown in Table 1. The present exemplary embodiment satisfies the Expressions (1) to (6), and achieves a photographing angle of view (angle of view) of 112.0° in the wide angle end to widen the angle of view. The present exemplary embodiment also achieves a

zoom lens which has various aberrations adequately corrected in the whole zooming region and has a high optical performance.

#### Exemplary Embodiment 4

FIG. 7 illustrates a sectional view of lenses at the time when a zoom lens of Exemplary Embodiment 4 (Numeric Embodiment 4) according to the present invention is set in a wide angle end and focuses on infinity. FIG. 8A illustrates views of longitudinal aberration at the time when the zoom lens is set in the wide angle end in Numeric Embodiment 4; FIG. 8B illustrates views of longitudinal aberration at the time when the focal length is set at 11.7 mm in Numeric Embodiment 4; and FIG. 8C illustrates views of longitudinal aberration at the time when the zoom lens is set in the telephoto end in Numeric Embodiment 4. Any view of the aberration is a view of the longitudinal aberration at the time when the zoom lens focuses on infinity.

In FIG. 7, the zoom lens has, in order from the object side to the image side, a first lens unit U1 for focusing, which has a negative refractive power. The zoom lens has further a second lens unit U2 for zooming, which moves to the object side during zooming from the wide angle end to the telephoto end and has a positive refractive power. The zoom lens has still a third lens unit U3 which moves non-linearly on the optical axis in synchronization with the movement of the second lens unit U2, corrects the variation of the image plane due to the zooming and has a negative refractive power. The zoom lens has still further a fourth lens unit U4 which does not move for zooming, performs an imaging operation, and has a positive refractive power.

Next, the first lens unit U1 in the present exemplary embodiment will be described. The first lens unit U1 corresponds to a first surface to a 14th surface. The first lens unit U1 includes: a first sub lens unit U1a having a negative refractive power which does not move for focusing; and a second sub lens unit U1b having a positive refractive power which moves to the image side when the focus is moved to an extremely close side from an infinity side. The first sub lens unit U1a includes, in order from the object side to the image side: a meniscus concave lens G1 which is convex toward the object side; a meniscus concave lens G2 which is convex toward the object side; a meniscus concave lens G3 which is convex toward the object side; a biconcave lens G4; and a meniscus convex lens G5 which is concave toward the image side. In addition, the first surface, the fifth surface and the sixth surface have an aspherical surface shape, and mainly correct distortion aberration and field curvature in the wide angle side. The second sub lens unit U1b includes: a biconvex lens G6; and a biconcave lens G7. The second lens unit U2 includes: a cemented lens of a biconvex lens and a meniscus concave lens which is convex toward the image side; and a biconvex lens. In addition, an 18th surface and a 19th surface have an aspherical surface shape, and mainly correct the variation of the spherical aberration due to the zooming. The third lens unit U3 includes: a cemented lens of a biconcave lens and a meniscus convex lens which is concave toward the image side. The fourth lens unit U4 includes a convex lens and a concave lens, and is formed of seven lenses as a whole. The values of the present exemplary embodiment, which correspond to each conditional expression, are shown in Table 1. The present exemplary embodiment satisfies the Expressions (1) to (6), and achieves a photographing angle of view (angle of view) of 120.0° in the wide angle end to widen the angle of view. The present exemplary embodiment also achieves a

15

zoom lens which has various aberrations adequately corrected in the whole zooming region and has a high optical performance.

#### Exemplary Embodiment 5

FIG. 9 illustrates a sectional view of lenses at the time when a zoom lens of Exemplary Embodiment 5 (Numeric Embodiment 5) according to the present invention is set in a wide angle end and focuses on infinity. FIG. 10A illustrates views of longitudinal aberration at the time when the zoom lens is set in the wide angle end in Numeric Embodiment 5; FIG. 10B illustrates views of longitudinal aberration at the time when the focal length is set at 36 mm in Numeric Embodiment 5; and FIG. 10C illustrates views of longitudinal aberration at the time when the zoom lens is set in a telephoto end in Numeric Embodiment 5. Any view of the aberration is a view of the longitudinal aberration at the time when the zoom lens focuses on infinity.

In FIG. 9, the zoom lens has, in order from the object side to the image side, a first lens unit U1 having a negative refractive power. The zoom lens has further a second lens unit U2 for zooming, which moves to the object side during zooming from the wide angle end to the telephoto end and has a positive refractive power. The zoom lens has still a third lens unit U3 which moves non-linearly on the optical axis in synchronization with the movement of the second lens unit U2, corrects the variation of the image plane due to the zooming, and has a negative refractive power. The zoom lens has still further a fourth lens unit U4 which does not move for zooming, performs an imaging operation, and has a positive refractive power.

Next, the first lens unit U1 in the present exemplary embodiment will be described. The first lens unit U1 corresponds to a first surface to an eighth surface. The first sub lens unit U1 includes, in order from the object side to the image side: a meniscus concave lens G1 which is convex toward the object side; a biconcave lens G2; a biconcave lens G3; and a meniscus convex lens G4 which is concave toward the image side. In addition, the first surface has an aspherical surface shape, and mainly corrects distortion aberration and field curvature in the wide angle side. The second lens unit U2 includes: a biconvex lens; a cemented lens of a biconvex lens and a meniscus concave lens which is convex toward the image side; and a biconvex lens. In addition, a 14th surface and a 15th surface have an aspherical surface shape, and mainly correct the variation of the spherical aberration due to zooming. The third lens unit U3 includes: a biconcave lens; and a cemented lens of a biconcave lens and a biconvex lens. A 16th surface has an aspherical surface shape, and mainly corrects the variation of the field curvature due to zooming. The fourth lens unit U4 includes: a 41 lens unit U4a which does not move for focusing; and a 42 lens unit U4b which moves to the object side when the focus is moved to an extremely close end side from an infinity side. The 41 lens unit U4a includes a cemented lens of a biconvex lens G1 and a meniscus concave lens G2 which is convex toward the object side. The 42 lens unit U4b includes a convex lens and a concave lens, and is formed of three lenses as a whole. The values of the present exemplary embodiment, which correspond to each conditional expression, are shown in Table 1. The present exemplary embodiment satisfies the Expressions (1) to (3), (5) and (6), and achieves a photographing angle of view (angle of view) of 81.6° at the wide angle end to widen the angle of view. The present exemplary embodiment also achieves the zoom lens which has various aberrations adequately corrected in the whole zooming region and has a high optical performance.

#### Exemplary Embodiment 6

FIG. 11 is a sectional view of lenses at the time when the zoom lens of Exemplary Embodiment 6 (Numeric Embodi-

16

ment 6) according to the present invention is set in a wide angle end and focuses on infinity. FIG. 12A illustrates views of longitudinal aberration at the time when the zoom lens is set in the wide angle end in Numeric Embodiment 6; FIG. 12B illustrates views of longitudinal aberration at the time when the focal length is set at 28 mm in Numeric Embodiment 6; and FIG. 12C illustrates views of longitudinal aberration at the time when the zoom lens is set in a telephoto end in Numeric Embodiment 6. Any view of the aberration is a view of the longitudinal aberration at the time when the zoom lens focuses on infinity.

In FIG. 11, the zoom lens has, in order from the object side to the image side, a first lens unit U1 for focusing, which has a negative refractive power. The zoom lens has further a second lens unit U2 which moves to the object side during zooming from the wide angle end to the telephoto end, and has a positive refractive power; and a fourth lens unit U4 having a positive refractive power. The zoom lens has still further a third lens unit U3 which moves non-linearly on the optical axis in synchronization with the movement of the second lens unit U2 and the fourth lens unit U4, corrects the variation of the image plane due to the zooming, and has a negative refractive power.

Next, the first lens unit U1 in the present exemplary embodiment will be described. The first lens unit U1 corresponds to a first surface to a tenth surface. The first lens unit U1 includes: a first sub lens unit U1a having a negative refractive power which does not move for focusing; and a second sub lens unit U1b having a negative refractive power which moves to the object side when the focus is moved to an extremely close side from an infinity side. The first sub lens unit U1a includes, in order from the object side to the image side: a meniscus concave lens G1 which is convex toward the object side; a biconcave lens G2; and a meniscus convex lens G3 which is concave toward the image side. In addition, the first surface has an aspherical surface shape, and mainly corrects distortion aberration and field curvature in the wide angle side. The second sub lens unit U1b includes: a biconvex lens G4; and a biconcave lens G5. The second lens unit U2 includes: a biconvex lens; a cemented lens of a biconcave lens and a biconvex lens; and a biconvex lens. In addition, a 16th surface and a 17th surface have an aspherical surface shape, and mainly correct the variation of the spherical aberration due to the zooming. The third lens unit U3 includes: a biconcave lens; and a cemented lens of a biconcave lens and a biconvex lens. The fourth lens unit U4 includes a convex lens and a concave lens, and is formed of five lenses as a whole. Furthermore, the fourth lens unit U4 is moved to the object side during zooming from a wide angle end to a telephoto end, and thereby aberration due to the zooming can be adequately corrected. In addition, the aperture stop approaches the object side in the telephoto end, and accordingly the height of the light beam of an off-axis light beam in a side closer to the object side than the aperture stop is reduced. As a result, the lens diameters of the second sub lens unit and the second lens unit can be reduced. The values of the present exemplary embodiment, which correspond to each conditional expression, are shown in Table 1. The present exemplary embodiment satisfies the Expressions (1) to (6), and achieves a photographing angle of view (angle of view) of 88.4° in the wide angle end to widen the angle of view. The present exemplary embodiment also achieves the zoom lens which has various aberrations adequately corrected in the whole zooming region and has a high optical performance.

Exemplary embodiments according to the present invention have been described above, but the present invention is not limited to these exemplary embodiments, and can be modified and changed in various ways in such a range as not to deviate from the scope.



Unit mm							
Surface number	r	d	nd	vd	$\theta_g F$	Effective diameter	Focal length
1*	69.91896	2.56500	1.772499	49.60	0.5521	64.133	-58.733
2	27.15350	12.46346				49.081	
3	49.07729	1.71000	1.763850	48.56	0.5594	44.998	-54.123
4	22.15839	14.36164				36.704	
5	-64.84229	1.71000	1.696797	55.53	0.5433	35.460	-37.787
6	45.13753	0.33776				34.844	
7	40.02401	4.44257	1.854780	24.80	0.6121	35.301	76.901
8	95.67024	1.98832				34.888	
9	94.98543	6.50372	1.595220	67.74	0.5442	34.734	57.965
10	-53.08890	0.18564				34.351	
11	-249.42636	1.71000	1.772499	49.60	0.5521	32.312	-74.800
12	75.90246	(Variable)				30.901	
13	52.07986	9.27522	1.620411	60.29	0.5426	32.175	33.656
14	-32.68704	1.20000	1.854780	24.80	0.6121	32.009	-77.109
15	-65.34371	0.17100				32.302	
16*	272.54183	5.14077	1.583126	59.38	0.5423	31.705	93.301
17*	-67.84118	(Variable)				31.379	
18	-57.79581	1.00000	1.882997	40.76	0.5667	17.043	-18.981
19	23.99271	3.27190	1.808095	22.76	0.6307	17.015	35.085
20	138.68879	(Variable)				17.056	
21 (Aperture stop)	$\infty$	1.97548				17.254	
22	34.91800	3.24931	1.589130	61.14	0.5406	17.687	53.408
23	-319.68817	7.00000				17.473	
24	54.11174	1.50000	1.800999	34.97	0.5863	15.900	-31.446
25	17.05312	4.40938	1.717362	29.50	0.6048	15.512	18.921
26	-61.70060	0.20000				15.710	
27	-162.07811	1.00000	1.800999	34.97	0.5863	15.701	-23.969
28	22.00702	3.71101	1.496999	81.54	0.5374	15.789	39.803
29	-190.19744	0.99405				16.210	
30	-692.87917	4.23771	1.496999	81.54	0.5374	16.503	34.107
31	-16.62727	1.28250	1.854780	24.80	0.6121	16.865	-35.327
32	-37.88640	42.84				17.790	
Image plane	$\infty$						
Data of aspherical surface							
First surface							
K = 0.00000e+000 A 4 = 4.17866e-006 A 6 = -1.92010e-009							
A 8 = 2.61505e-012 A10 = -1.54892e-015 A12 = 6.85390e-019							
Sixteenth surface							
K = 0.00000e+000 A 4 = -9.59888e-006 A 6 = 1.81600e-008							
A 8 = -1.07471e-010 A10 = 2.56594e-013 A12 = -2.92447e-016							
Seventeenth surface							
K = 0.00000e+000 A 4 = -7.03453e-006 A 6 = 2.19484e-008							
A 8 = -1.21795e-010 A10 = 3.13899e-013 A12 = -3.71003e-016							
Various data							
Zoom ratio 2.50							
	Wide angle		Middle		Telephoto		
Focal length	12.50		18.75		31.25		
F-number	3.50		3.50		3.50		
Half angle of view	51.21		39.67		26.45		
Height of image	15.55		15.55		15.55		
Total lens length	193.59		193.59		193.59		
BF	42.84		42.84		42.84		
d12	28.20		18.14		10.94		
d17	1.65		17.73		40.53		
d20	23.30		17.28		1.68		
Position of entrance pupil	27.36		29.48		32.93		
Position of exit pupil	-23.47		-23.47		-23.47		
Position of front principal point	37.50		42.93		49.45		
Position of rear principal point	30.34		24.09		11.59		

-continued

Unit mm					
Data of zoom lens unit					
Unit	Leading surface	Focal length	Lens structure length	Position of front principal point	Position of rear principal point
1	1	-17.60	47.98	12.07	-23.60
2	13	37.30	15.79	5.20	-5.13
3	18	-40.80	4.27	0.63	-1.68
4	21	41.98	29.56	4.49	-18.44

## Numeric Embodiment 2

Unit mm							
Surface number	r	d	nd	vd	0gF	Effective diameter	Focal length
1*	145.17014	3.00000	1.772499	49.60	0.5521	69.566	-48.598
2	29.67131	20.27934				51.793	
3	-83.50875	2.00000	1.696797	55.53	0.5433	51.023	-46.709
4	54.23801	0.20000				49.760	
5	51.45567	6.07171	1.854780	24.80	0.6121	50.184	95.067
6	130.50000	2.99205				49.753	
7	225.36754	7.87693	1.496999	81.54	0.5374	49.592	108.104
8	-69.99417	0.15369				49.343	
9	-267.94137	2.00000	1.772499	49.60	0.5521	47.353	-147.091
10	199.59718	(Variable)				46.379	
11	-154856.85999	5.13719	1.516330	64.14	0.5352	49.352	229.481
12	-118.83885	0.20000				50.068	
13	85.50323	12.83275	1.595220	67.74	0.5442	51.557	58.118
14	-55.16316	2.00000	1.854780	24.80	0.6121	51.297	-134.175
15	-107.13276	0.20000				51.619	
16*	258.24126	5.32192	1.583126	59.38	0.5423	50.221	180.038
17*	-176.74761	(Variable)				49.486	
18	-72.43254	1.00000	1.651597	58.55	0.5426	26.470	-67.149
19	112.26397	1.20000				25.326	
20	-148.48145	1.00000	1.834000	37.16	0.5775	25.356	-38.301
21	41.15553	4.25211	1.805181	25.42	0.6161	24.723	42.579
22	-207.22494	(Variable)				24.370	
23 (Aperture stop)	$\infty$	2.29891				23.173	
24	56.83698	3.99881	1.729157	54.68	0.5444	23.596	48.435
25	-91.55085	1.20000	1.720467	34.70	0.5834	23.373	-100.163
26	354.00250	17.77415				23.134	
27	116.29624	1.20000	1.654115	39.70	0.5737	22.570	-222.919
28	64.60211	3.60724	1.496999	81.54	0.5374	22.788	84.629
29	-119.30244	6.75821				23.161	
30	85.22775	6.17293	1.438750	94.93	0.5343	24.628	44.555
31	-24.88647	0.38396				24.695	
32	-24.69675	1.20000	1.720467	34.70	0.5834	24.486	-53.370
33	-69.60366	43.27				25.184	
Image plane	$\infty$						
Data of aspherical surface							
First surface							
K = 0.00000e+000 A 4 = 2.50679e-006 A 6 = -7.99208e-010 A 8 = 4.81444e-013 A10 = -1.74689e-016 A12 = 3.59817e-020							
Sixteenth surface							
K = 0.00000e+000 A 4 = -2.17519e-006 A 6 = 3.05858e-009 A 8 = -2.68615e-012 A10 = 2.33037e-015 A12 = 8.32786e-019							
Seventeenth surface							
K = 0.00000e+000 A 4 = -1.97934e-006 A 6 = 3.49219e-009 A 8 = -3.16130e-012 A10 = 2.73213e-015 A12 = 7.64582e-019							

-continued

Unit mm					
Various data Zoom ratio 2.81					
			Wide angle	Middle	Telephoto
Focal length			16.00	26.88	45.00
F-number			2.80	2.80	2.80
Half angle of view			44.18	30.05	19.06
Height of image			15.55	15.55	15.55
Total lens length			247.38	247.38	247.38
BF			43.27	43.27	43.27
d10			40.43	22.58	13.00
d17			2.46	31.99	66.12
d22			38.90	27.22	2.67
Position of entrance pupil			33.77	41.26	51.29
Position of exit pupil			-50.57	-50.57	-50.57
Position of front principal point			47.04	60.44	74.72
Position of rear principal point			27.27	16.39	-1.73
Data of zoom lens unit					
Unit	Leading surface	Focal length	Lens structure length	Position of front principal point	Position of rear principal point
1	1	-30.60	44.57	7.50	-26.30
2	11	52.50	25.69	8.67	-8.23
3	18	-58.50	7.45	-0.19	-4.95
4	23	52.44	44.59	16.78	-25.89

## Numeric Embodiment 3

Unit mm							
Surface number	r	d	nd	vd	θgF	Effective diameter	Focal length
1*	98.81978	2.56500	1.772499	49.60	0.5521	65.783	-42.607
2	24.49801	14.92817				46.449	
3	53.43399	1.71000	1.696797	55.53	0.5433	41.674	-43.396
4	19.10829	13.55157				32.471	
5	-52.94064	1.71000	1.696797	55.53	0.5433	31.164	-31.297
6	37.85240	0.19983				30.654	
7	34.72560	4.52580	1.854780	24.80	0.6121	30.989	57.683
8	107.91960	1.94919				30.611	
9	55.04475	6.27760	1.487490	70.23	0.5300	30.280	56.804
10	-54.00646	0.19202				29.743	
11	-635.45495	1.71000	1.834000	37.16	0.5775	28.174	-66.863
12	61.63147	(Variable)				27.299	
13	32.18839	10.47861	1.487490	70.23	0.5300	29.720	33.632
14	-30.04932	1.20000	1.846660	23.78	0.6205	29.264	-108.851
15	-45.19363	0.20000				29.519	
16*	113.36465	4.94151	1.583126	59.38	0.5423	28.257	75.478
17*	-71.25404	(Variable)				27.512	
18	-66.26307	1.00000	1.882997	40.76	0.5667	17.157	-18.045
19	21.28891	3.42625	1.808095	22.76	0.6307	17.030	32.119
20	104.96393	(Variable)				17.020	
21(Aperture stop)	∞	3.00972				17.226	
22	23.82123	3.99006	1.589130	61.14	0.5406	17.814	35.019
23	-148.75008	0.61888				17.374	
24	-55.41955	1.00000	2.000690	25.46	0.6133	17.291	-16.972
25	25.04187	4.31536	1.922860	18.90	0.6495	17.145	17.872
26	-45.94351	0.20000				17.107	
27	-59.27785	1.00000	1.800999	34.97	0.5863	16.946	-21.035
28	23.94160	5.46854	1.496999	81.54	0.5374	16.670	25.565
29	-25.17361	3.75678				16.784	
30	56.21741	4.98165	1.496999	81.54	0.5374	17.430	28.175
31	-18.16856	1.00000	1.854780	24.80	0.6121	17.657	-32.009
32	-54.44478	41.28				18.411	
Image plane	∞						

-continued

Unit mm					
Data of aspherical surface					
First surface					
K = 0.00000e+000 A 4 = 8.06357e-006 A 6 = -7.33504e-009 A 8 = 9.49818e-012 A10 = -6.69349e-015 A12 = 2.48987e-018					
Sixteenth surface					
K = 0.00000e+000 A 4 = -1.73308e-005 A 6 = 3.37473e-008 A 8 = -2.63337e-010 A10 = 9.40008e-013 A12 = -9.53132e-016					
Seventeenth surface					
K = 0.00000e+000 A 4 = -1.03271e-005 A 6 = 4.81257e-008 A 8 = -3.14294e-010 A10 = 1.21513e-012 A12 = -1.47785e-015					
Various data					
Zoom ratio 2.00					
	Wide angle	Middle	Telephoto		
Focal length	10.50	15.23	21.00		
F-number	3.00	3.00	3.00		
Half angle of view	55.97	45.61	36.52		
Height of image	15.55	15.55	15.55		
Total lens length	177.73	177.73	177.73		
BF	41.28	41.28	41.28		
d12	16.97	10.07	6.06		
d17	1.17	14.83	28.49		
d20	18.40	11.64	1.98		
Position of entrance pupil	22.99	24.27	25.54		
Position of exit pupil	-25.69	-25.69	-25.69		
Position of front principal point	31.84	36.04	39.95		
Position of rear principal point	30.78	26.06	20.28		
Data of zoom lens unit					
Unit	Leading surface	Focal length	Lens structure length	Position of front principal point	Position of rear principal point
1	1	-12.20	49.32	11.96	-22.67
2	13	30.90	16.82	5.87	-6.00
3	18	-40.20	4.43	0.83	-1.56
4	21	40.17	29.34	9.89	-12.56

40

## Numeric Embodiment 4

Unit mm							
Surface number	r	d	nd	vd	θgF	Effective diameter	Focal length
1*	166.07091	3.50000	1.772499	49.60	0.5521	69.122	-38.336
2	25.00244	15.65668				47.006	
3	58.38991	2.00000	1.696797	55.53	0.5433	40.443	-44.473
4	20.01482	10.42841				31.410	
5*	296.67411	1.40000	1.583126	59.38	0.5423	27.667	-58.414
6*	30.61118	7.08107				24.330	
7	-54.28971	1.20000	1.438750	94.93	0.5343	23.760	-56.039
8	45.45125	0.19986				23.631	
9	28.65621	3.38892	1.846660	23.78	0.6034	24.570	65.669
10	55.33305	1.98071				24.341	
11	52.98182	5.27110	1.516330	64.14	0.5352	24.700	46.573
12	-42.82707	0.19776				24.596	
13	-183.85075	1.20000	1.834000	37.16	0.5775	23.936	-50.553
14	55.32533	(Variable)				23.486	
15	24.01800	9.15521	1.516330	64.14	0.5352	24.055	25.293
16	-25.10305	1.20000	1.805181	25.42	0.6161	23.001	-66.702
17	-47.75887	0.20000				22.740	
18*	368.86885	3.59632	1.583126	59.38	0.5423	21.560	69.679
19*	-45.70235	(Variable)				20.283	
20	-66.25563	1.00000	1.882997	40.76	0.5667	15.089	-12.655
21	13.63110	4.03194	1.854780	24.80	0.6121	14.854	16.947
22	173.27617	(Variable)				14.758	

-continued

Unit mm							
23 (Aperture stop)	$\infty$	1.49724				14.694	
24	53.54771	3.97931	1.589130	61.14	0.5406	14.661	25.771
25	-20.71801	1.00000	1.910820	35.25	0.5824	14.416	-13.379
26	30.77153	0.20000				14.522	
27	20.36752	4.18435	1.805181	25.42	0.6161	14.930	18.942
28	-57.21607	0.20000				14.753	
29	-464.62521	1.00000	1.800999	34.97	0.5863	14.529	-15.992
30	13.27762	5.05220	1.496999	81.54	0.5374	13.971	20.128
31	-35.86192	1.25710				14.872	
32	-162.01537	5.13891	1.487490	70.23	0.5300	15.904	26.357
33	-12.06668	1.00000	1.854780	24.80	0.6121	16.701	-45.881
34	-18.02300	37.98				17.999	
Image plane	$\infty$						
Data of aspherical surface							
First surface							
K = 0.00000e+000 A 4 = 1.16496e-005 A 6 = -1.37512e-008							
A 8 = 1.55219e-011 A10 = -9.48947e-015 A12 = 2.72161e-018							
Fifth surface							
K = 0.00000e+000 A 4 = 1.23089e-006 A 6 = 1.58453e-007							
A 8 = -2.93819e-010 A10 = -9.70645e-013 A12 = 3.14980e-015							
Sixth surface							
K = 0.00000e+000 A 4 = 3.33504e-005 A 6 = 6.65742e-008							
A 8 = 1.30829e-009 A10 = -7.64884e-012 A12 = 1.58200e-014							
Eighteenth surface							
K = 0.00000e+000 A 4 = -1.12452e-005 A 6 = 1.46196e-007							
A 8 = -2.42732e-010 A10 = 6.73558e-012 A12 = -1.33966e-014							
Nineteenth surface							
K = 0.00000e+000 A 4 = 8.37535e-006 A 6 = 1.64809e-007							
A 8 = -7.11266e-012 A10 = 4.39885e-012 A12 = 5.34610e-015							
Various data							
Zoom ratio 1.50							
	Wide angle		Middle		Telephoto		
Focal length	9.00		11.70		13.50		
F-number	2.90		2.90		2.90		
Half angle of view	59.94		53.04		49.04		
Height of image	15.55		15.55		15.55		
Total lens length	156.79		156.79		156.79		
BF	37.98		37.98		37.98		
d14	15.27		8.79		5.86		
d19	1.14		8.83		14.09		
d22	5.20		4.00		1.67		
Position of entrance pupil	21.61		22.08		22.44		
Position of exit pupil	-25.28		-25.28		-25.28		
Position of front principal point	29.33		31.62		33.06		
Position of rear principal point	28.98		26.28		24.48		
Data of zoom lens unit							
Unit	Leading surface	Focal length	Lens structure length	Position of front principal point	Position of rear principal point		
1	1	-10.00	53.50	12.83	-24.67		
2	15	26.60	14.15	4.55	-5.45		
3	20	-48.90	5.03	0.70	-1.96		
4	23	43.94	24.51	15.06	-2.36		

Unit mm							
Surface number	r	d	nd	vd	θgF	Effective diameter	Focal length
1*	122.98756	3.00000	1.696797	55.53	0.5433	77.200	-73.457
2	35.88815	28.76364				60.474	
3	-983.76737	2.00000	1.516330	64.14	0.5352	50.478	-197.692
4	114.44384	4.80848				48.005	
5	-140.00941	2.00000	1.589130	61.14	0.5406	47.896	-77.264
6	68.19706	0.05717				46.285	
7	61.35970	5.48450	1.805181	25.42	0.6161	46.774	141.043
8	126.76209	(Variable)				46.835	
9	133.52188	9.39853	1.496999	81.54	0.5374	52.915	114.547
10	-97.41700	0.17467				53.201	
11	74.19099	13.22655	1.438750	94.93	0.5343	51.969	80.376
12	-63.85836	2.00000	1.854780	24.80	0.6121	50.923	-143.472
13	-133.80088	0.20000				51.078	
14*	218.51676	6.75488	1.583126	59.38	0.5423	50.216	118.781
15*	-100.84106	(Variable)				50.008	
16*	-38.76564	1.00000	1.583126	59.38	0.5423	21.866	-41.169
17	64.33231	2.50000				20.633	
18	-42.23901	1.00000	1.882997	40.76	0.5667	20.471	-37.021
19	150.05360	3.78925	1.755199	27.51	0.6103	20.561	39.199
20	-36.86642	(Variable)				20.653	
21(Aperture stop)	∞	1.97983				18.180	
22	56.18245	5.18489	1.487490	70.23	0.5300	18.521	34.494
23	-23.38333	1.20000	1.548141	45.79	0.5685	18.454	-60.106
24	-81.00659	25.19314				18.475	
25	68.40261	4.42842	1.496999	81.54	0.5374	21.928	137.314
26	108773.02770	6.75821				22.270	
27	195.13284	5.14940	1.496999	81.54	0.5374	23.300	54.459
28	-31.25500	2.11614				23.443	
29	-28.62267	1.20000	1.903660	31.32	0.5946	22.763	-56.735
30	-65.47272	45.03				23.371	
Image plane	∞						

## Data of aspherical surface

## First surface

K = 0.00000e+000 A 4 = 1.19748e-006 A 6 = -1.01092e-010  
A 8 = 2.64659e-014 A10 = 2.61525e-017 A12 = -4.38423e-021

## Fourteenth surface

K = 0.00000e+000 A 4 = -2.04406e-006 A 6 = 1.89826e-009  
A 8 = -4.25645e-012 A10 = 3.33347e-015 A12 = -1.72266e-018

## Fifteenth surface

K = 0.00000e+000 A 4 = -1.30309e-006 A 6 = 2.29967e-009  
A 8 = -4.87658e-012 A10 = 4.07050e-015 A12 = -1.88237e-018

## Sixteenth surface

K = 0.00000e+000 A 4 = 4.51838e-006 A 6 = 9.87511e-009  
A 8 = -1.68427e-010 A10 = 1.18905e-012 A12 = -3.25353e-015

Various data  
Zoom ratio 4.00

	Wide angle	Middle	Telephoto
Focal length	18.00	36.00	72.00
F-number	4.00	4.00	4.00
Half angle of view	40.82	23.36	12.19
Height of image	15.55	15.55	15.55
Total lens length	265.17	265.17	265.17
BF	45.03	45.03	45.03
d 8	38.04	16.77	7.02
d15	2.43	35.62	72.78
d20	40.30	28.38	0.98
Position of entrance pupil	43.57	59.32	83.92
Position of exit pupil	-57.20	-57.20	-57.20
Position of front principal point	58.40	82.64	105.21
Position of rear principal point	27.03	9.03	-26.97

-continued

Unit mm					
Data of zoom lens unit					
Unit	Leading surface	Focal length	Lens structure length	Position of front principal point	Position of rear principal point
1	1	-33.10	46.11	15.22	-19.75
2	9	47.78	31.75	11.21	-11.52
3	16	-43.53	8.29	-2.15	-8.60
4	21	53.63	53.21	15.77	-34.87

## Numeric Embodiment 6

Unit mm							
Surface number	r	d	nd	vd	θgF	Effective diameter	Focal length
1*	76.00463	3.50000	1.772499	49.60	0.5521	72.084	-60.643
2	28.48353	22.08135				53.240	
3	-205.17955	2.50000	1.651597	58.55	0.5426	51.048	-57.709
4	46.49354	2.75498				46.595	
5	44.98637	4.94085	1.654115	39.70	0.5737	46.855	154.287
6	77.25988	13.54376				46.073	
7	176.88727	4.75286	1.717362	29.50	0.6048	44.481	125.299
8	-183.64728	3.80595				43.815	
9	-78.45720	2.50000	1.589130	61.14	0.5406	42.017	-103.570
10	282.67057	(Variable)				40.737	
11	122.74585	6.17776	1.595220	67.74	0.5442	41.860	118.593
12	-164.35557	0.20000				42.143	
13	-916.62183	2.00000	1.805181	25.42	0.6161	42.138	-85.989
14	75.71908	7.69391	1.496999	81.54	0.5374	42.233	90.284
15	-107.18472	0.20000				42.605	
16*	72.03817	8.00176	1.583126	59.38	0.5423	42.698	73.109
17*	-101.14319	(Variable)				42.196	
18	-58.31172	1.00000	1.589130	61.14	0.5406	25.054	-58.774
19	86.61403	2.00000				24.984	
20	-124.67051	1.00000	1.834000	37.16	0.5775	25.048	-39.497
21	45.32366	4.37210	1.854780	24.80	0.6121	25.632	42.127
22	-175.42974	(Variable)				25.954	
23(Aperture stop)	∞	0.98743				26.356	
24	46.68453	4.11669	1.696797	55.53	0.5433	26.847	62.101
25	-605.86282	11.14904				26.548	
26	108.99092	1.20000	1.654115	39.70	0.5737	23.120	-46.536
27	23.80112	5.38307	1.496999	81.54	0.5374	22.256	39.031
28	-98.53064	6.75821				21.901	
29	73.61813	5.17741	1.438750	94.93	0.5343	22.174	46.241
30	-27.50019	1.20000	1.720467	34.70	0.5834	22.221	-48.360
31	-129.61057	(Variable)				22.720	
Image plane	∞						
Data of aspherical surface							
First surface							
K = 0.00000e+000 A 4 = 1.93169e-006 A 6 = -2.07535e-010 A 8 = 5.80702e-013 A10 = -3.53624e-016 A12 = 1.73149e-019							
Sixteenth surface							
K = 0.00000e+000 A 4 = -1.58493e-006 A 6 = 4.93078e-009 A 8 = -1.62831e-011 A10 = 2.94648e-014 A12 = -2.40387e-017							
Seventeenth surface							
K = 0.00000e+000 A 4 = -8.21603e-007 A 6 = 5.37705e-009 A 8 = -1.82082e-011 A10 = 3.38552e-014 A12 = -2.74747e-017							
Various data							
Zoom ratio 2.62							
			Wide angle	Middle	Telephoto		
Focal length			16.00	28.00	42.00		
F-number			2.60	2.60	2.60		

Unit mm					
Half angle of view	44.18	29.05	20.32		
Height of image	15.55	15.55	15.55		
Total lens length	231.09	231.09	231.09		
BF	39.99	41.02	43.98		
d10	29.37	9.57	1.99		
d17	2.73	31.58	54.18		
d22	30.00	19.92	1.94		
d31	39.99	41.02	43.98		
Position of entrance pupil	37.41	44.27	49.54		
Position of exit pupil	-31.85	-31.85	-31.85		
Position of front principal point	49.84	61.51	68.28		
Position of rear principal point	23.99	13.02	1.99		

Data of zoom lens unit					
Unit	Leading surface	Focal length	Lens structure length	Position of front principal point	Position of rear principal point
1	1	-28.00	60.38	13.73	-31.93
2	11	48.20	24.27	10.10	-6.16
3	18	-55.50	8.37	-0.39	-6.02
4	23	49.26	35.97	5.86	-25.20

TABLE 1

Conditional expression	Numeric Embodiment					
	1	2	3	4	5	6
(1) $f1/f2$	-0.472	-0.583	-0.395	-0.376	-0.693	-0.581
(2) $f2/f3$	-0.914	-0.897	-0.769	-0.544	-1.098	-0.868
(3) $ m2/m3 $	0.799	0.757	0.664	2.667	0.789	1.138
(4) $ f11/f12 $	0.068	0.070	0.040	0.025	—	0.040
(5) $(\theta1p - \theta1n)/(v1p - v1n)$	-2.29E-03	-2.32E-03	-2.29E-03	-1.47E-03	-2.19E-03	-1.83E-03
(6) $(\theta2p - \theta2n)/(v2p - v2n)$	-1.99E-03	-1.84E-03	-2.06E-03	-2.13E-03	-1.38E-03	-1.69E-03
m2	-17.265	-27.425	-10.905	-9.416	-31.024	-27.383
m3	21.618	36.233	16.415	3.530	39.324	24.061
f11	-15.434	-27.161	-11.451	-9.589	—	-31.728
f12	225.346	387.441	287.190	376.094	—	-802.576

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2013-164807, filed Aug. 8, 2013, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. A zoom lens comprising, in order from an object side to an image side:

- a first lens unit having a negative refractive power which does not move for zooming;
- a second lens unit having a positive refractive power which moves during the zooming;
- a third lens unit having a negative refractive power which moves during the zooming; and
- a fourth lens unit having a positive refractive power, wherein the following expressions are satisfied:

$$-0.80 < f1/f2 < -0.25,$$

$$-1.2 < f2/f3 < -0.4, \text{ and}$$

$$0.5 < |m2/m3| < 3.0,$$

where f1 represents a focal length of the first lens unit, f2 represents a focal length of the second lens unit, f3 represents

a focal length of the third lens unit, m2 represents a moving amount of the second lens unit during the zooming from a wide angle end to a telephoto end, and m3 represents a moving amount of the third lens unit during the zooming from the wide angle end to the telephoto end.

2. The zoom lens according to claim 1,

wherein the first lens unit comprises a first sub lens unit having a negative refractive power which does not move for focusing, and a second sub lens unit which moves during the focusing; and

wherein the following conditional expression is satisfied:

$$0.005 < |f11/f12| < 0.150,$$

where f11 represents a focal length of the first sub lens unit and f12 represents a focal length of the second sub lens unit.

3. The zoom lens according to claim 1, wherein the fourth lens unit or a lens unit of a part of the fourth lens unit is moved during the focusing.

4. The zoom lens according to claim 1, wherein a front sub lens unit which does not move for the focusing out of lenses that constitute the first lens unit comprises one or more convex lenses and two or more concave lenses, with a lens closest to the object side in the front sub lens unit being a concave lens, with a lens closest to the image side in the front sub lens unit being a convex lens.

5. The zoom lens according to claim 4, wherein the following conditional expression is satisfied,

$$-2.50 \times 10^{-3} < (\theta1p - \theta1n)/(v1p - v1n) < -1.30 \times 10^{-3},$$



## 33

where  $v_{1p}$  and  $\theta_{1p}$  represent average values of an Abbe number and a partial dispersion ratio of the convex lenses which constitute the front sub lens unit respectively, and  $v_{1n}$  and  $\theta_{1n}$  represent average values of an Abbe number and a partial dispersion ratio of the concave lenses, respectively, and where an Abbe number  $v$  and a partial dispersion ratio  $\theta$  are respectively expressed by

$$v=(Nd-1)/(NF-NC),$$

$$\theta=(Ng-NF)/(NF-NC),$$

where  $N_g$  represents a refractive index in a g-line,  $N_F$  represents a refractive index in an F-line,  $N_d$  represents a refractive index in a d-line, and  $N_C$  represents a refractive index in a C-line.

6. The zoom lens according to claim 1, wherein the second lens unit comprises two or more convex lenses and one or more concave lenses, and wherein the following conditional expression is satisfied,

$$-2.30 \times 10^{-3} < (\theta_{2p} - \theta_{2n}) / (v_{2p} - v_{2n}) < -1.20 \times 10^{-3},$$

where  $v_{2p}$  and  $\theta_{2p}$  represent average values of an Abbe number and a partial dispersion ratio of the convex lenses which constitute the second lens unit, respectively, and  $v_{2n}$  and  $\theta_{2n}$  represent average values of an Abbe number and a partial dispersion ratio of the concave lenses, respectively.

7. The zoom lens according to claim 1, wherein the second lens unit includes a lens having an aspherical surface on at least one surface.

## 34

8. An image pickup apparatus comprising:  
a zoom lens comprising, in order from an object side to an image side:  
a first lens unit having a negative refractive power which does not move for zooming;  
a second lens unit having a positive refractive power which moves during the zooming;  
a third lens unit having a negative refractive power which moves during the zooming; and  
a fourth lens unit having a positive refractive power, wherein the following expressions are satisfied:

$$-0.80 < f_1/f_2 < -0.25,$$

$$-1.2 < f_2/f_3 < -0.4, \text{ and}$$

$$0.5 < |m_2/m_3| < 3.0,$$

where  $f_1$  represents a focal length of the first lens unit,  $f_2$  represents a focal length of the second lens unit,  $f_3$  represents a focal length of the third lens unit,  $m_2$  represents a moving amount of the second lens unit during the zooming from a wide angle end to a telephoto end, and  $m_3$  represents a moving amount of the third lens unit during the zooming from the wide angle end to the telephoto end; and

an image pickup element which photoelectrically converts an optical image formed by the zoom lens.

\* \* \* \* \*